DEVELOPMENT OF METHOLOGY FOR SEISMIC DESIGN OF CONCRETE GRAVITY DAM

A thesis submitted in partial fulfillment of the requirements for the degree of

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In

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By

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Under the guidance of

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CERTIFICATE

This is to certify that this report entitled, "**DEVELOPMENT OF METHOLOGY FOR SEISMIC DESIGN OF CONCRETE GRAVITY DAM**" submitted by **Pratik Patra (110CE0575)** in partial fulfillment of the requirement for the award of Bachelor of Technology Degree in Civil Engineering at National Institute of Technology, Rourkela is an authentic work carried out by him under my supervision.

To the best of my knowledge, the matter embodied in this report has not been submitted to any other university/institute for the award of any degree or diploma.

Dr. Pradip Sarkar

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(Research Guide)

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PRATIK PATRA

ABSTRACT

Keywords: *Concrete Gravity Dam, Earthquake analysis, Seismic load, ANSYS software, Base Shear, Spatial Distribution of Base Shear.*

Earthquake analysis and earthquake resistance design of dams is of major importance because of the catastrophic consequences if such a structure is to fail. In India we don't have any guidelines to take into account the seismic load for the analysis of Dam. In the absence of any well-defined method, design offices generally use an empirical method which does not consider the dynamic properties of dam and different earthquake zone. This study is an attempt to develop guidelines to consider seismic force for the analysis of concrete gravity dam. An equivalent static method for seismic design of concrete gravity dam is developed considering the dynamic properties of the dam as well as different earthquake zones. For this to achieve, a family of concrete gravity Dam with varying height, base-width and side slope is analyzed using finite element software ANSYS. Dams are modeled with 2-D plane strain elements. Dynamic properties of all the selected dams are evaluated. A regression analysis is carried out on the modal properties obtained from the finite element analysis in order to develop empirical relation between time period, height and base width. The minimum number of modes that must be taken into for the analysis is decided by considering the mass participation ratios. Design base shear is calculated by using the Design horizontal acceleration spectrum value and Seismic weight of the building. A method is proposed to distribute the calculated base shear over the height of the Dam.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

NOTATIONS

SYMBOLS

V_B	Base Shear
W	Seismic weight of the dam
g	Acceleration due to gravity
α_h	Effect Horizontal Acceleration
k_h	Acceleration Coefficient
H_{Max}	Maximum height of the dam
f	Permissible Stress in Concrete
υ_w	Unit Weight of water
S_c	Specific gravity of Concrete
T_1	1^{st} Natural Time period
T_2	2^{nd} Natural Time period
b	Base width of the Dam
h	Height of the Dam
A_h	Horizontal Seismic Coefficient
Z	Zone Factor given in Table 2 of IS1893
I	Importance Factor
R	Response Reduction Factor
$\frac{S_a}{g}$	Spectral Acceleration Coefficient
Q(h)	Shear force at height h
A(h)	Area at height h
P_{Crest}	Point load at top of the Dam

CHAPTER ~ 1

INTRODUCTION

1.1 BACKGROUND AND MOTIVATION

Basically, a concrete gravity dam is defined as a structure, which is designed in such a way that its own weight resists the external forces. It is primarily the weight of a gravity dam which prevents it from being overturned when subjected to the thrust of impounded water. This type of structure is durable, and requires very little maintenance. Gravity dams typically consist of a non-overflow section(s) and an overflow section or spillway. The two general concrete construction methods for concrete gravity dams are conventional placed mass concrete and RCC. Gravity dams, constructed in stone masonry, were built even in ancient times, most often in Egypt, Greece, and the Roman Empire.

However, concrete gravity dams are preferred these days and mostly constructed. They can be constructed with ease on any dam site, where there exists a natural foundation strong enough to bear the enormous weight of the dam. Such a dam is generally straight in plan, although sometimes, it may be slightly curve. The line of the upstream face of the dam or the line of the crown of the dam if the upstream face in sloping, is taken as the reference line for layout purposes, etc. and is known as the “Base line of the Dam” or the “Axis of the Dam”. When suitable conditions are available, such dams can be constructed up to great heights. The ratio of base width to height of high gravity dams is generally less than 1:1. But the earlier dams are constructed with the ratio of about 1.5 to 3. This is due to the low grade of concrete and low density of compaction achieved.

Engineers in India must pay special and careful attention to the problem of earthquake loading in the design and evaluation of almost all permanent civil engineering structures. The significant effects caused by earthquakes on dams are not only those directly related to the seismic motions but also those directly associated with the ground displacement along the fault line. In the country with 5,100 large dams and 1,040 active faults covering 57% of land mass making prone to earthquakes, there is always a possibility that a severe earthquake in highly seismic zones might affect the performance of dam. However, analyzing dam for seismic forces is not a simple problem. Like all other structure, concrete gravity dam requires nonlinear, dynamic and probabilistic study to evaluate the internal forces due to seismic loading.

It is not always possible to obtain rigorous mathematical solutions for engineering problem. In fact, analytical solution can be obtained only for certain simplified situations. For the Problems involving complex material properties, loading and boundary conditions, the engineer introduce assumptions and idealization deemed necessary to make the problem mathematically manageable, but still capable of providing sufficiently approximate solutions and the satisfactory results from point of view of safety and economy. The link between the real physical system and the mathematically feasible solution is provided by the mathematical model which is the symbolic designation for the substitute idealized system including all the assumptions imposed on the physical problem.

Dynamic analysis of Buildings and Dams are very complex phenomena. In order to solve this complex phenomenon, we use mathematical modal including all the assumptions imposed on the physical problem. However, unlike building and other structures, there is no simplified standard procedure to analyze concrete gravity dam for seismic loading. This is the underlying motivation of the present study.

1.2 OBJECTIVE

Prior to defining the specific objectives of the present study, a detailed literature review was taken up. This is discussed in detail in the Chapter 2. Based on the literature review, the main objective of the present study is defined as to develop an equivalent static method for seismic analysis of concrete gravity dam suitable for design office. Its includes

1. Method to calculate fundamental period and design base shear
2. Vertical distribution of base shear along the height of the dam

1.3 SCOPE OF WORK

The scope of this study is limited to:

A. The cross sections of concrete gravity dams are generally uniform throughout its longitudinal direction and perpendicular to the longitudinal axis. The present study is based on analysis of two-dimensional (2D) models of a typical cross-section of the dam. Analysis of three-dimensional solid model is kept outside the scope of the present study.

B. Most of the existing concrete gravity dams are located on hard-rock. Therefore, fixed support condition is assumed at the base of the dam for all the analysis of the present study. Interaction between soil and structure is ignored.

C. To get a conservative estimation of the seismic forces only free-standing dam models were analyzed in the present study. Interaction between fluid and structure ignored as this may result a higher natural period and thereby under-estimate the base shear of the dam.

D. Typical material properties (similar to that of Bhakra Dam) have been considered for all the dams studied here. Therefore, the results and the conclusions of the present study may be specific to these particular material properties. Variation in material properties strictly call for probabilistic analysis. However, this is kept outside the scope of the present study.

1.4 OUTLINE OF THE PRESENT WORK

The present study mainly deals with the Dam and its behavior under Seismic load. A family of concrete gravity Dam is taken into account for the analysis. In order to simulate the problem to real life, an existing concrete gravity dam called Bhakra Dam is taken for analysis. The 2D model of the Dam is analyzed in finite element software ANSYS 13.0. All the modal parameter of the dam is extracted from the software. After doing the regression analysis, an empirical formula has established to calculate the *natural time period* and *base shear*. After that a spatial distribution of the base shear over the height is studied.

This thesis contains 5 chapters.

Chapter 1 has presented the background, objective and scope of the present study.

Chapter 2 starts with a description of the previous work done on dynamic analysis of concrete gravity dam by other researchers. A brief description about other methods that are available for the seismic analysis of concrete gravity dam is also discussed. Later in the chapter, design methodology of concrete gravity Dam is discussed. This chapter also explains the different loads that are acting on the gravity Dam. Finally this chapter discusses on the practical profile of Dam and distinguishes between low gravity dam and high gravity dam.

Chapter 3 has presented the stepwise procedure for 2D modeling of concrete gravity dam using finite element package ANSYS 13.0.

Chapter 4 presents the results obtained in the present study and associated discussions. The first part of this chapter discusses the modal analysis results of Bhakra Dam. The remaining part of this chapter presents the result of the regression analysis on different dynamic parameters of selected concrete gravity dam.

Finally, Chapter 5 presents a summary including salient features, significant conclusions from this study and the future scope of research in this area.

CHAPTER ~ 2

LITERATURE REVIEW

2.1 GENERAL

The first part of this chapter describes briefly some important aspect of concrete gravity dam, *e.g.*, typical cross section profiles, types of loads and conventional design methodology etc.

A detailed literature review in this subject reveals no published literature on the equivalent static analysis of concrete gravity dam. However, there is few research efforts found where typical concrete gravity dams were analyses by response history and time history analysis. The last part of this chapter presents the findings of these researches. This chapter also summarizes the seismic coefficient method of analyzing concrete gravity dam as reported in some textbooks.

2.2 CONCRETE GRAVITY DAM

A typical cross-section of a concrete gravity dam is shown in Fig. 2.1. The upstream face may by kept throughout vertical or partly slanting for some of its length as shown. A drainage gallery may be provided in order to relieve the uplift pressure exerted by the seeping water. Fig. 2.2 presents photograph of an existing concrete gravity dam

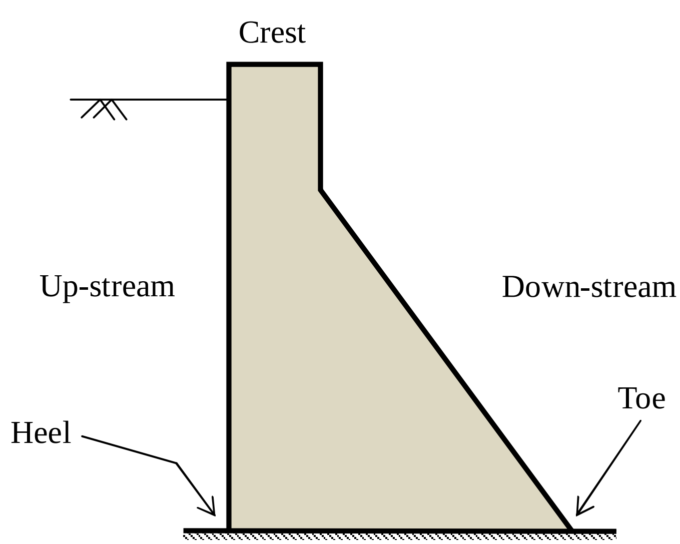


Fig. 2.1: Typical cross-section of concrete gravity dam

Fig 2.2: A Photo of Concrete Gravity Dam (Image Source from Internet)

Many loads act over the gravity dam in lateral and vertical direction. These loads are summarized as follows:

- Self-weight of the dam
- Surcharge or live load on the dam
- Ice Pressure
- Uplift Pressure
- Water Pressure from the Upstream and downstream
- Earthquake load on Dam
- Slit Pressure
- Wave Pressure

Some of these forces are deterministic and some others are probabilistic. Similarly some of the loads are static and some others are dynamic. Depending upon the complexity of the load and its effects there are defined methodologies to analyze the dam subjected to a particular load. Earthquake load is one of most complexes among the above list as it offers a dynamic and probabilistic character. Also, severe earthquake is expected to load the dam structure beyond its yielding level. At present there is no well-defined method available to analyze the dam for seismic load. In the absence of well definite design method, most dam are designed either without or inappropriate earthquake load.

In case of conventional analysis for static loads, criteria for structural stability have to be checked for following modes of failure:

1. Overturning or rotation about the toe.
2. Sliding
3. Development of tension.

2.3 ANALYSIS OF DAM AGAINST EARTHQUAKE FORCES

In India for seismic design is based on the standard IS 1893 issued by Bureau of Indian Standard, New Delhi. Revised IS 1893 is planned to have five parts as follows:

a) Part 1: Building and General Guidelines (2002)
b) Part 2: Liquid retaining tanks (?)
c) Part 3: Bridges and retaining walls (?)
d) Part 4: Industrial Structures (2004)

e) Part 5: Dams and embankments (?)

Two of this five parts (Part – 1 and 4) have already been published. However, other three parts are in the queue. Earlier version of this code IS 1893: 1984 was based on seismic coefficient method although it does not give any recommendation for the analysis of dam.

In absence of any structured guideline the designers used to either ignore the seismic force or follow the seismic coefficient method (prescribed for building structure in previous version of Indian Standard IS 1983:1984). Garg (2013) has recommended Eq. (2.1) for calculating the seismic base shear of concrete gravity dam.

$$V_B = \left(\frac{W}{g}\right)\alpha_h = \left(\frac{W}{g}\right)k_h g = Wk_h \tag{2.1}$$

Where, V_B is the design base shear, W is the total weight of concrete gravity dam and k_h is a coefficient based on the height of the dam. k_h for taller dam is taken as 0.1 whereas for shorter dam this is taken as 0.2.

As per Garg (2013) the total base shear is expressed as a fraction of total load which is to be applied laterally as a point load at the mass center to evaluate the internal forces. However, there are serious shortcomings of this approach. It does not consider the potential earthquake zones while calculating the base shear. Also, this method is not supported by dynamic characteristics of the dam structure. The height-wise distribution of the base shear proposed here is not scientific.

2.4 PROFILE OF THE DAM FOR PRACTICAL CONSIDERATIONS

Dynamic properties of any structures are function of its mass and stiffness distribution. Again, the stiffness and mass distribution is defined by the geometric profile of the structure. If we assume the gravity dam is uniform along its longitudinal axis then the cross-sectional profile plays an important role for dynamic properties of the dam. Fig. 2.3 presents a typical section of a low gravity Dam (Garg, 2013).

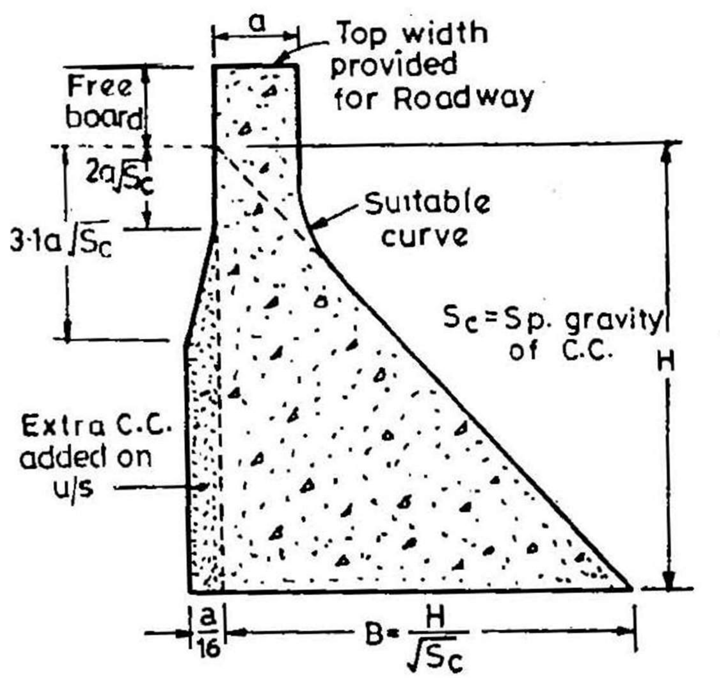


Fig 2.3: Typical section of a low gravity Dam (ref. Garg, 2013)

Garg (2013) proposed following relation to distinguish the low and high gravity dam.

$$H_{\lim} = \frac{f}{\gamma_w (s_c + 1)} \tag{2.2}$$

Where, $H_{\lim}$ is the limiting height below which the dam is considered to be a low gravity dam and above which the dam is considered to be high gravity dam. f is the permissible stress in the concrete, γ_w is the unit weight of the water and s_c is the specific gravity of concrete. For a dam of the height more than $H_{\lim}$ the compressive strength of the concrete at the bottom of the Dam will be high. In order to reduce this high compressive strength the base width is to be increased.

2.5 RESEARCH ON SEISMIC ANALYSIS OF CONCRETE GRAVITY DAM

A detailed literature review in the seismic analysis of concrete gravity dam revealed five papers.

A two-stage procedure has been proposed by Løkke (2013) for the elastic analysis phase of seismic design and safety evaluation of concrete gravity dams: (i) response spectrum analysis (RSA) and (ii) response history analysis (RHA) of a finite element idealization of the dam monolith. Both analysis procedures include the effects of dam-water foundation interaction. These procedures are added to computer software EAGD-84 and MATLAB program.

Leclerc *et. al*. (2002) presents the main features and organization of CADAM, a computer program that has been developed for the static and seismic stability evaluations of concrete gravity dams. CADAM is based on the gravity method using rigid body equilibrium and beam theory to perform stress analyses, compute crack lengths, and safety factors.

Seismic hazard assessment of roller compacted concrete (RCC) gravity dam is investigated by Thanoon (2008) considering the effects of dam-reservoir-foundation-sediment-interface interaction. Using finite and infinite element coupled method; two-dimensional seismic analysis is performed to investigate the seismic response of RCC gravity dam. The results of nonlinear elasto-plastic analysis demonstrate that the maximum tensile stress occurs at the base of the dam on the upstream heel.

A dam is modeled and analyzed by Das *et. al.* (2011) with the help of ALTAIR HYPERWORKS 10 software and the seismic response is evaluated for a Koyna Earthquake ground acceleration data and the seismic response are computed for hydrodynamic pressure force for the duration of earthquake.

Yamaguchi *et. al.* (2004) discusses the role of nonlinear dynamic analyses in seismic evaluation problems for concrete gravity dam. A two-dimensional section of a concrete gravity dam is evaluated using various linear and nonlinear procedures and it serves as case study for the discussion.

The literatures discussed here have studied the response of typical dams using improved and complex analysis procedures. However, there are no general guidelines reported to analyze a dam using simple linear-static idealization. Also, the computer software’s developed and reported in the published literature will not be useful for practical design of concrete gravity dam.

CHAPTER ~ 3

MODELING USING ANSYS 13.0

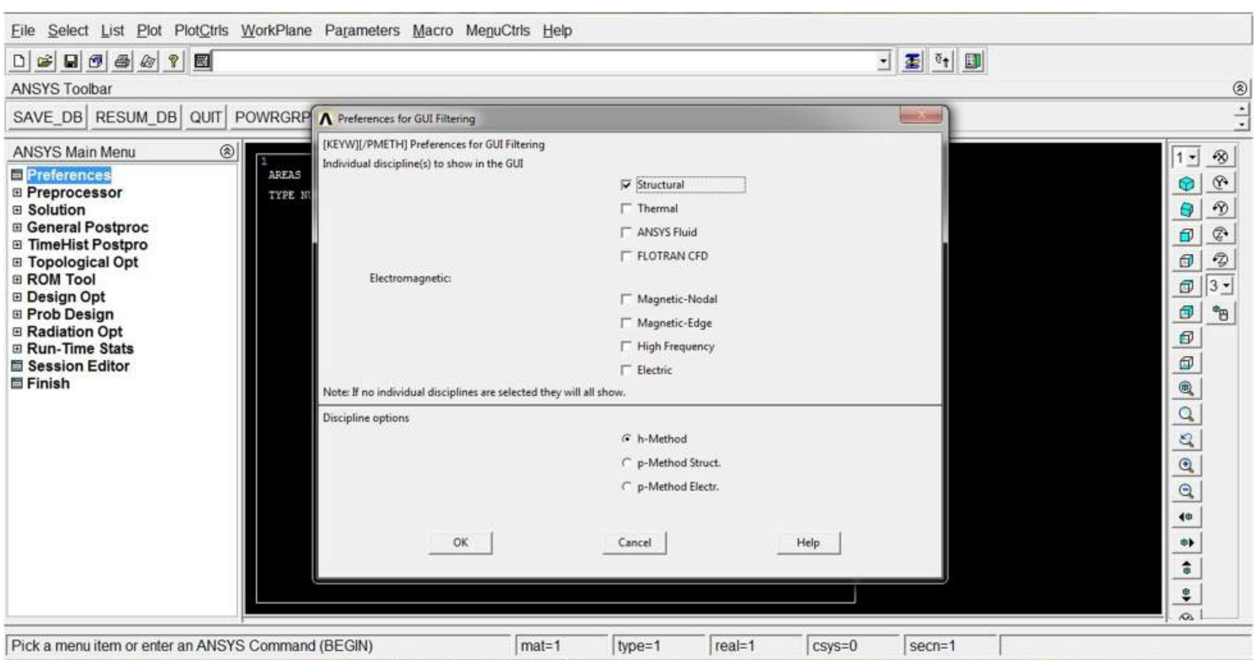
3.1 ANSYS MODEL

The 2D cross-section of the dam was modeled using a commercially available finite element package, ANSYS 13.0 according to ANSYS user's manual. The natural frequencies and mode shapes of the 2D dam model are obtained by modal analysis. The element type used is 'Solid 8 node 183 plane strain' solid elements which is an 8 noded structural shell, suitable for analyzing thin to moderately thick structures. The element has 8 nodes with 6 degrees of freedom at each node. The whole domain is divided into 8×8 meshes for all the cases. The boundary condition is given fixed at the bottom of the Dam. This condition closely resembled the field situation.

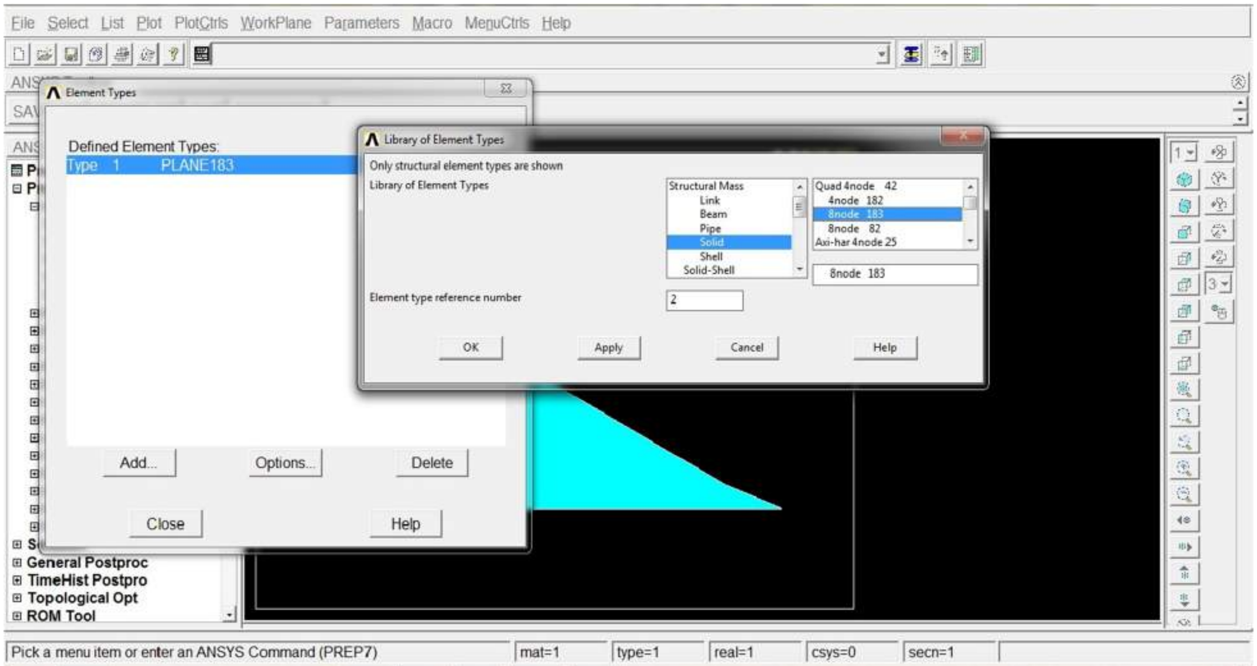
3.2 PROCEDURAL STEPS FOR MODELLING

The step by step procedure for modeling the dam in ANSYS 13.0 is explained as follows:

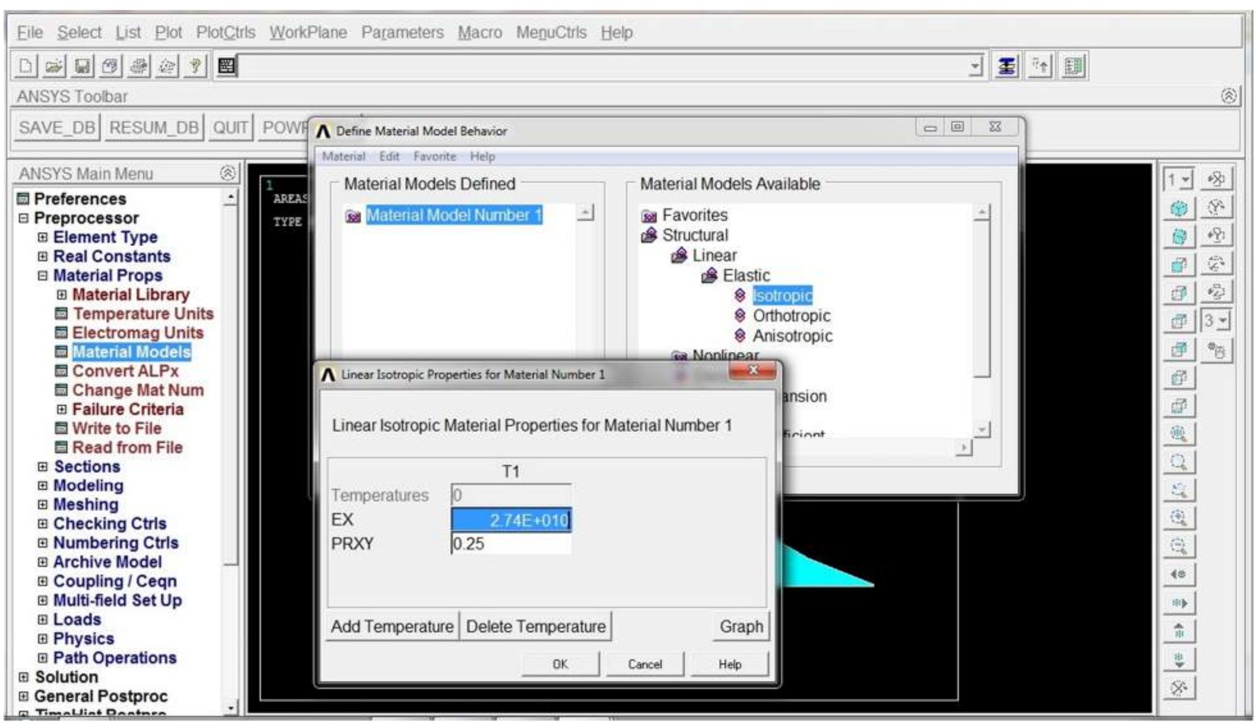
1. Preferences →Structural →Ok



2. Preprocessor→Element type→Add→Solid→Shell→8node 183→Ok

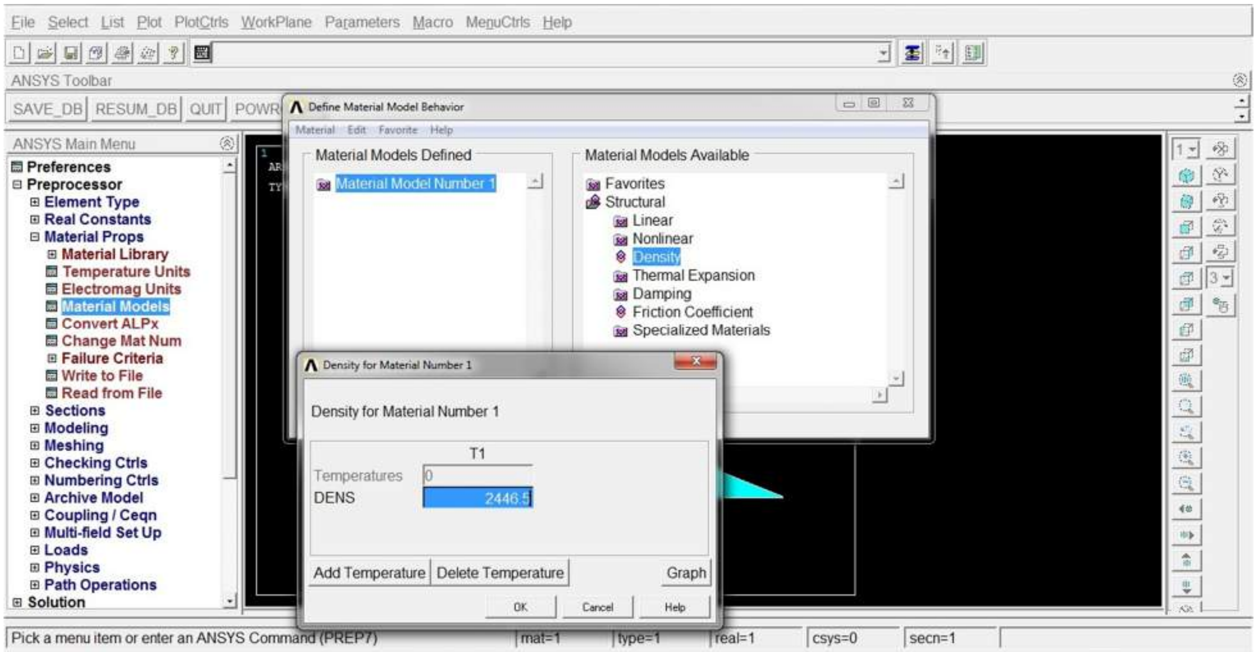


3. Preprocessor→Material Properties→Material Models→Structural→Linear→Elastic→Isotropic

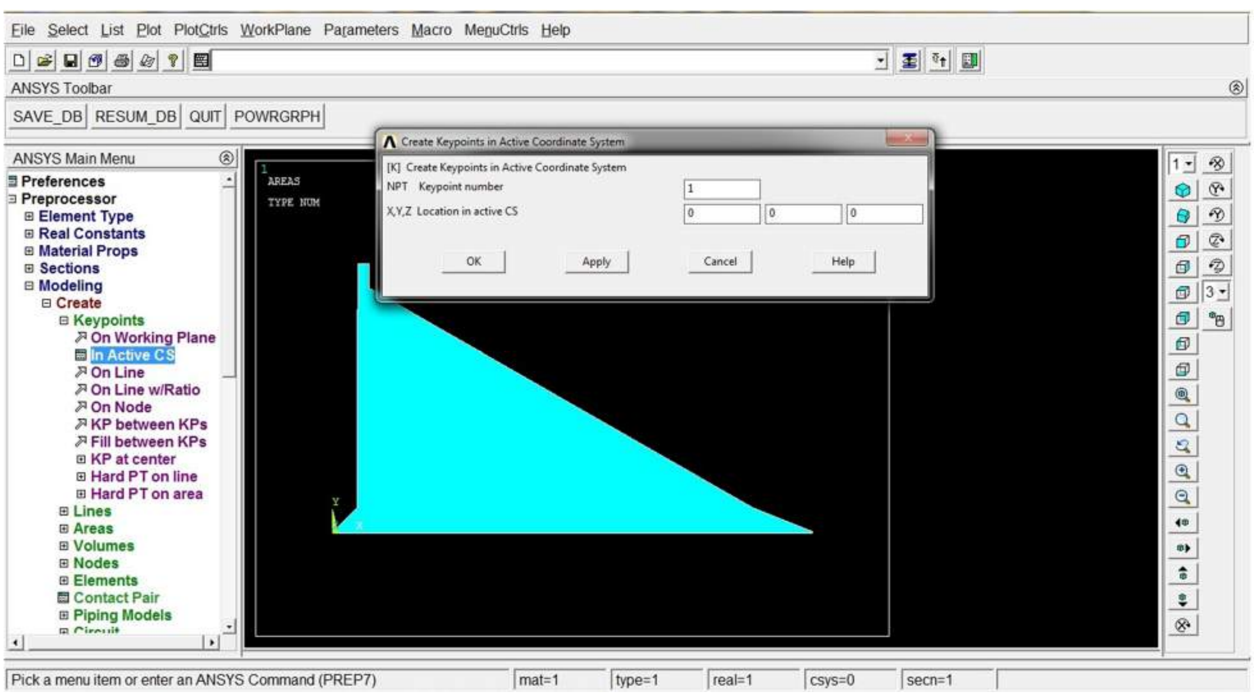


4. Enter the Linear Isotropic Material Properties and press Ok.

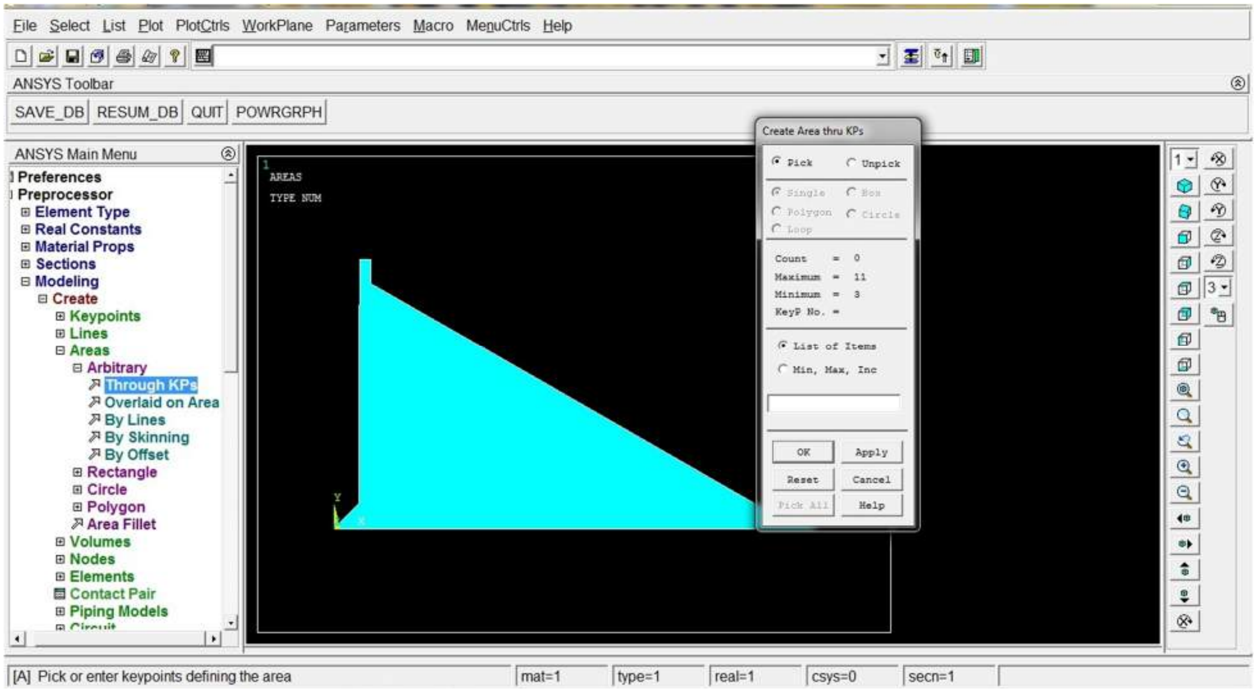
5. Material Models Available→Density→Enter the density of the Dam→Ok



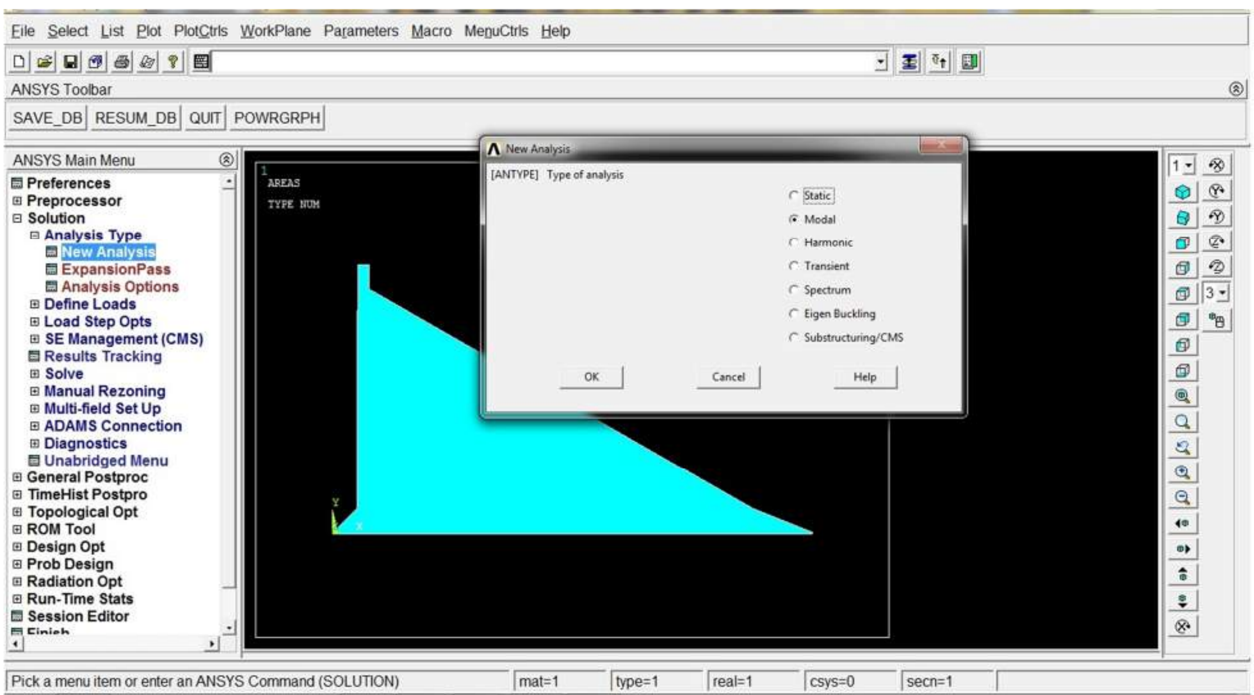
6. Preprocessor→Modeling→Create→Key points→In Active CS→Center the coordinate's →Ok



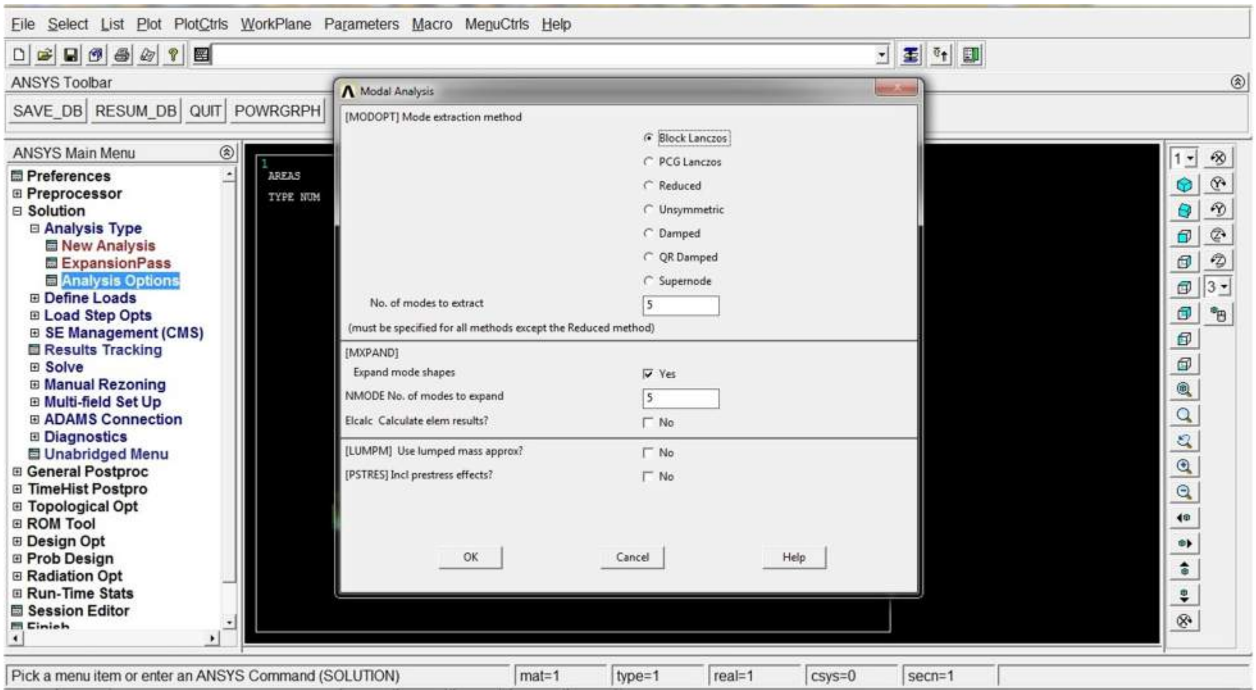
7. Preprocessor →Modeling →Create→Areas→Arbitary→Through KPs



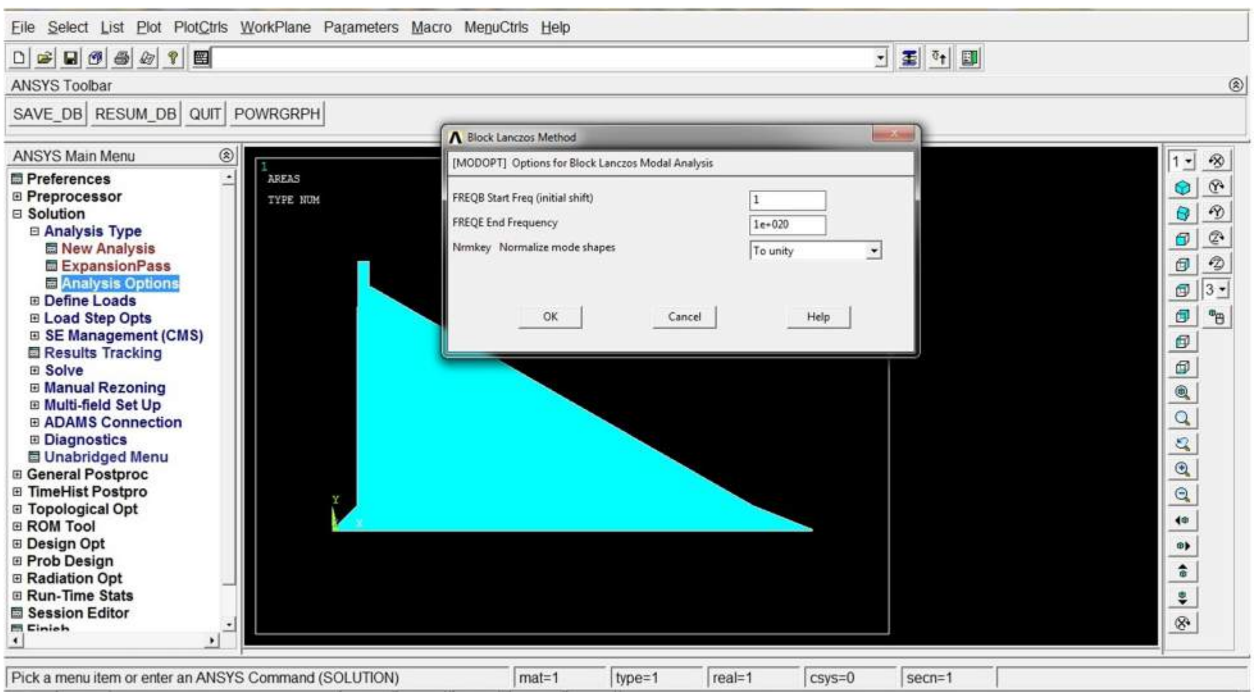
8. Solution →Loads →Analysis Type →New Analysis →Type of analysis – Modal →Ok



9. Solution →Loads →Analysis Type →Analysis Options →Mode extraction method – Block Lanczos →No. of modes to extract - 5 →Ok

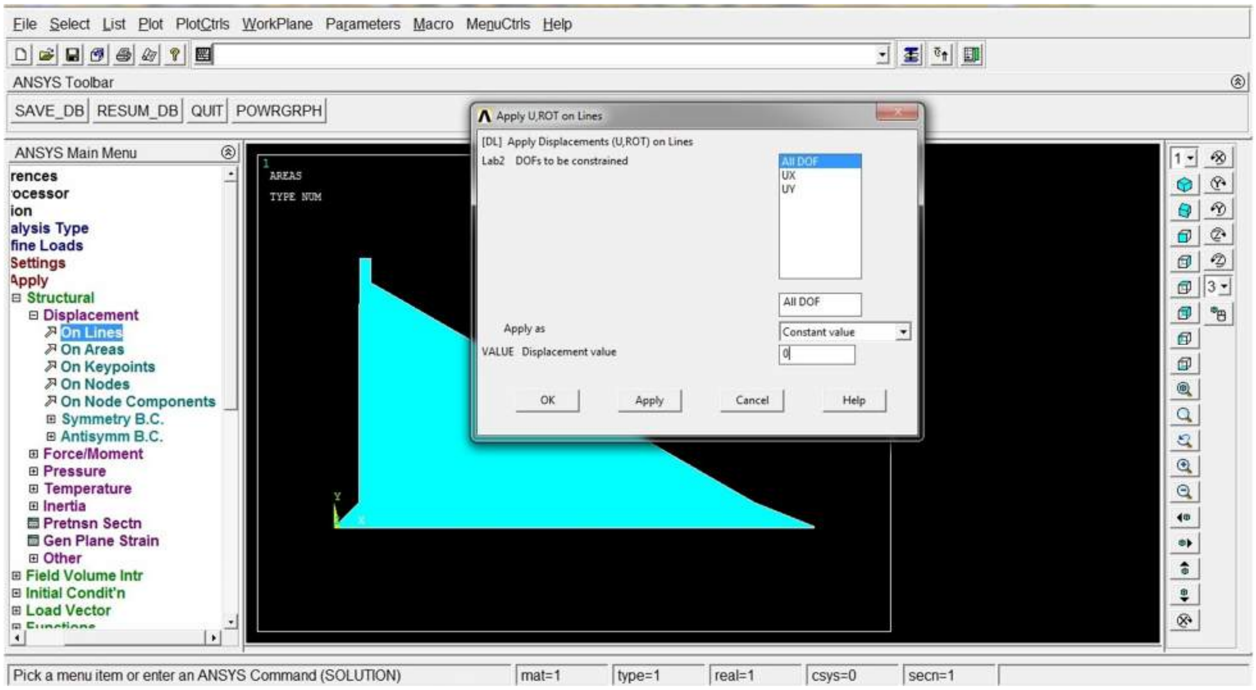


10.Block Lanczos Method →Enter the start and end frequency →Ok



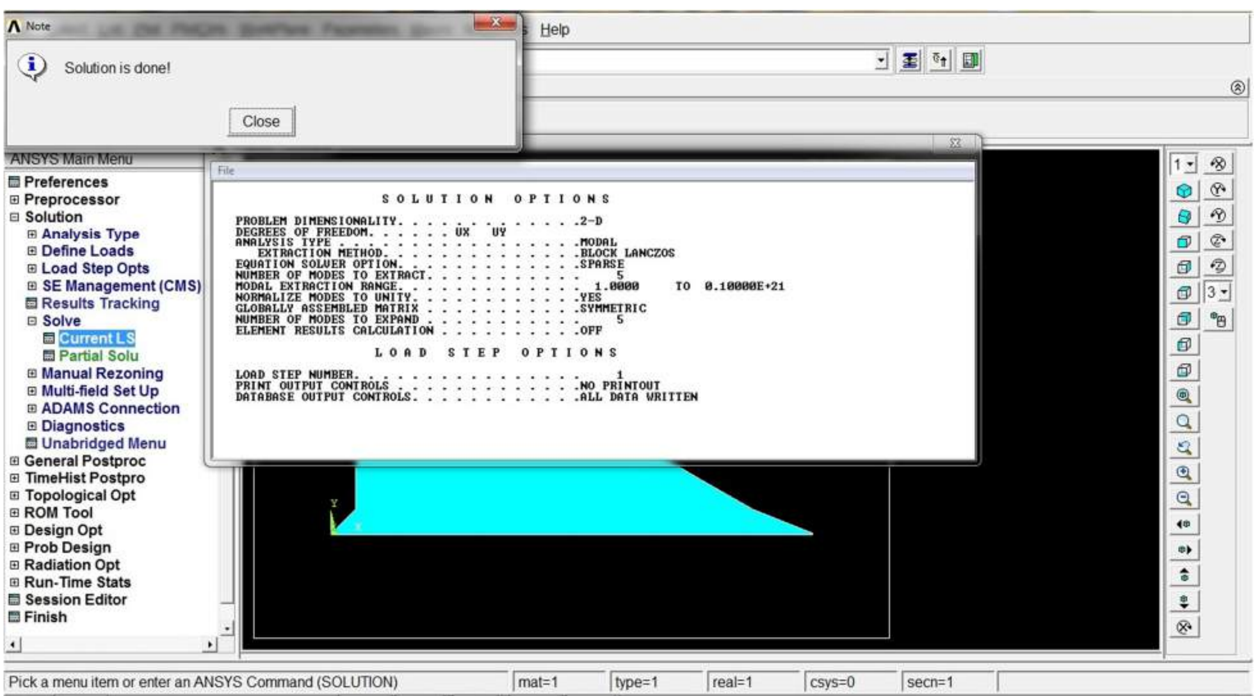
11. Solution →Define load→ Structural→Displacement→ On Lines →Ok

12. Enter the degree of Freedom to be constrained.



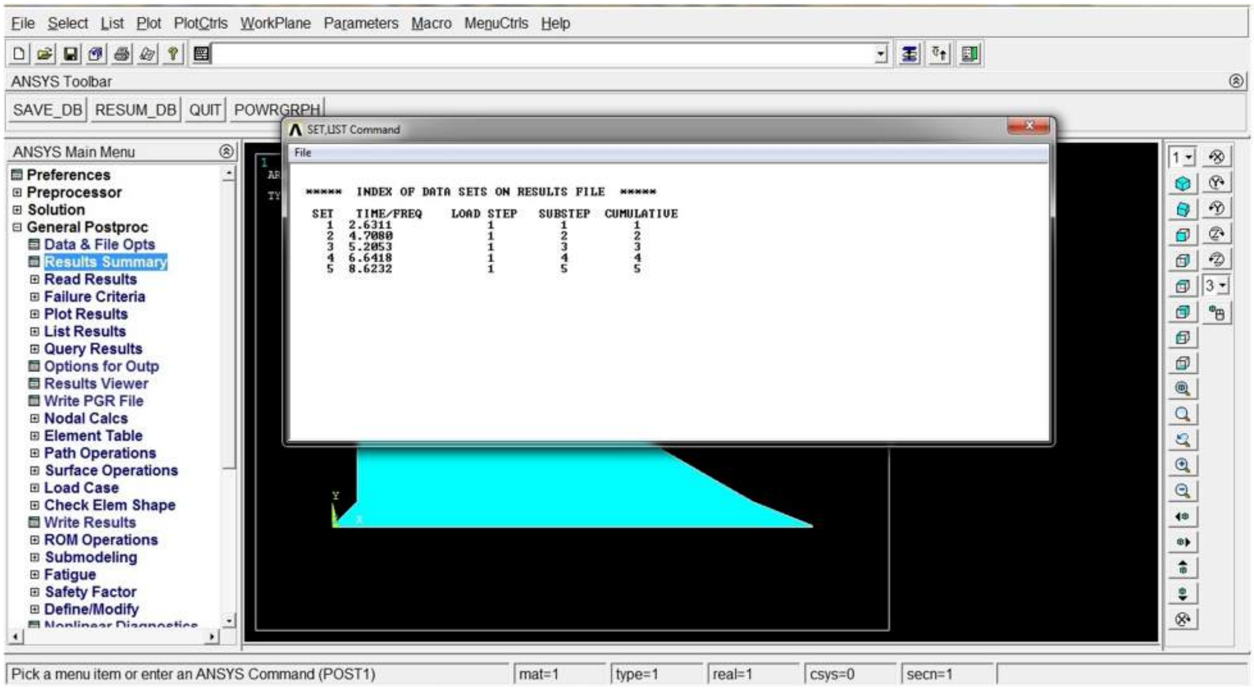
13. Solution →Solve →Current LS →Press ok in the Solve Current Load Step window

Once the solution is done a window displaying that solution is done is displayed. Close the window.



14. For viewing the results, follow the step given below:

General Postprocessing →Results Summary



15. Steps to get nodal displacement.

Select entities→Node→Line→Ok→Select line→Plot line →Select entities→Nodes→ Attached to→Lines all→Reselect→Ok→Plot node → General post.→Read result→First set→List Result→Nodal solution→Dof Solution→Disp. Vector Sum.→ Ok

CHAPTER ~ 4

RESULTS AND DISCUSSIONS

4.1 MODAL ANALYSIS OF BHAKRA DAM

4.1.1 Bhakra Dam

Bhakra dam, a concrete gravity dam, is 740 feet (226m) high, spanning the V-shaped gorge in the lower Shivalik hills, across Satluj river. The dam is 1700 feet long at the top and only 325 feet at the bottom. The width of the dam at the foundation is 1320 ft and it tapers to 30 ft at the top where a road runs. Bhakra dam was the highest concrete gravity dam of the world when built, thus surpassing the existing 221 m high Hoover dam. But the highest concrete gravity dam of the world, at present, is Grand Dixence dam in Switzerland (284 m high). Bhakra dam is situated in the Himachal Pradesh State of India near a village used to be called as Bhakra. It has been constructed on Satluj River. Satluj River coming from Himalaya is a Perennial river but carries enormous water during floods and rain.

Fig 4.1: Photoview of Bhakra Dam

4.1.2 Properties of Bhakra Dam

Depending on the material availability and dimensions, grade of the concrete is decided for the construction of dam. After getting the grade of the concrete all the properties of the dam are determined such as specific gravity of concrete, density of concrete etc. Detail material properties of the Bhakra Dam were not available in literature. These were assumed for all the analyses carried out in the present study and listed in Table 4.1:

Table 4.1: Assumed material properties for the Bhakra Dam

Parameters	Magnitudes
Grade of Concrete	M 30
The maximum allowable compressive stress in concrete	7 MPa
Specific gravity of concrete	2.4
Elastic Modulus	27.4 GPa
Density	2446.48 kg/m^3
Unit weight of water	10 kN/m^3

The height (226 m) and width (403 m) of the Bhakra Dam is obtained from literature (Garg, 2013). For the given height and the assumed material properties the Bhakra Dam comes under the category of high concrete gravity dam as per Eq. (2.2) given in Chapter 2. Hence, the dimensions of the Bhakra Dam are calculated according to the high gravity dam profile as per Section 2.4 given in Chapter 2. Fig. 4.2 shows a typical cross section of Bhakra Dam model analyzed in the present study. The details of the dimensions and other useful data about Bhakra Dam are also listed in Table 4.2.

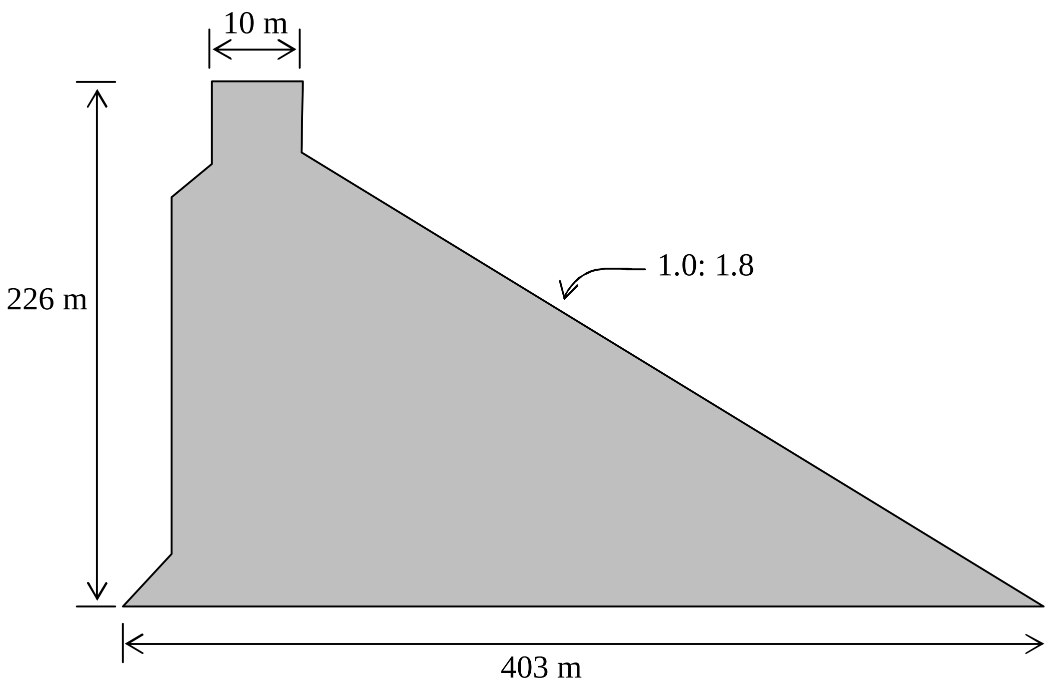


Fig 4.2: A Typical cross-section of Bhakra Dam (Garg, 2013)

Table 4.2: Some details about Bhakra Dam

Height of the dam	226 m
Length at the bottom	99 m
Length at the top	366 m
Width at the bottom	403 m
Width at the top	10 m
Concrete required for the dam	55,00,000 cubic yard
Electricity generated	1200 MW
Name of the Reservoir	Govind Sagar
Maximum Depth	226 m
Minimum depth	91 m
Total irrigation	10 million Acre of area
Population of these villages	30,000
Total storage capacity	8 million acre ft
Catchment area	22,000 sq. miles
Live storage	6.35 million acre ft
No. of Inspection galleries	46

4.1.3 Computer (FE) Model of Bhakra Dam

The dam is modeled in FE software ANSYS and analyzed to obtain modal parameters. The details step by step procedures for modeling and modal analysis is explained in Section 3.2 in Chapter 3. Solid 8 node 183 plane strain solid element was used model the dam and a convergence study was carried out to arrive at the number of elements. The ANSYS model of the Bhakra Dam is shown in the Fig. 4.3.

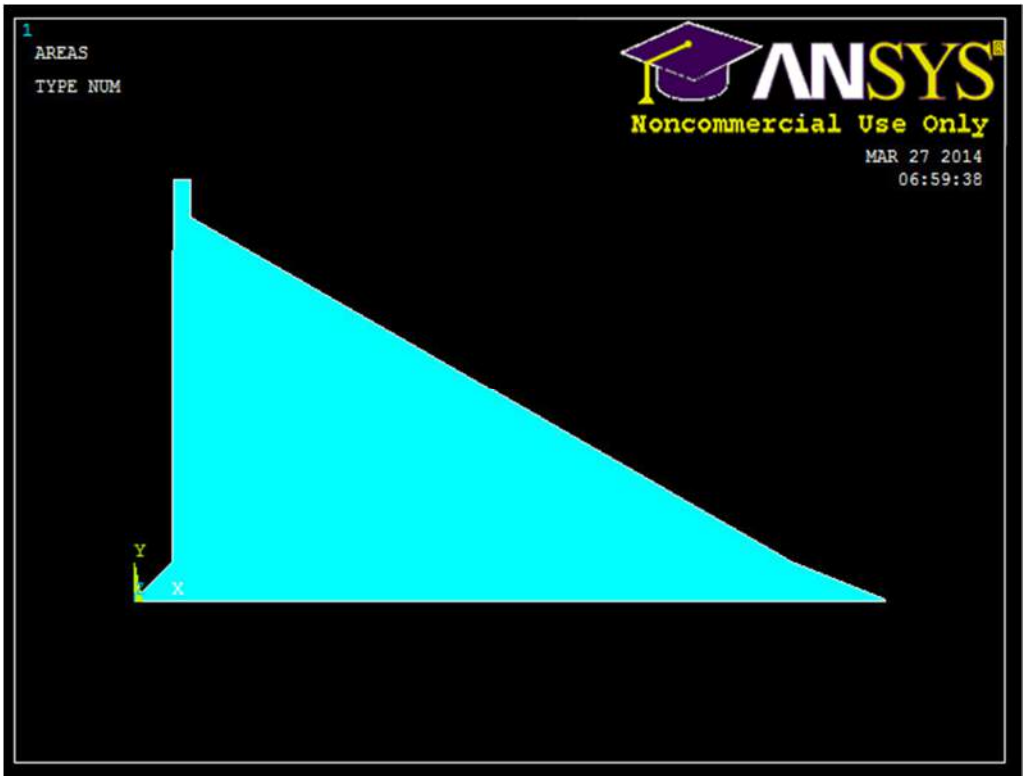


Fig. 4.3: FE Model of Bhakra Dam in ANSYS

4.1.4 Modal Properties of Bhakra Dam

After entering all the parameter that is required for the modal analysis, click on the Slove→Current LS to get its solution. A window will appear showing “Solution is done”. If this window is not coming then recheck the program again till this window appears. In order to get modal mass ratio type *GET, Par, MODE, N, PFACT in the command window. The modal parameter that extracted from this analysis is given in table 4.3.

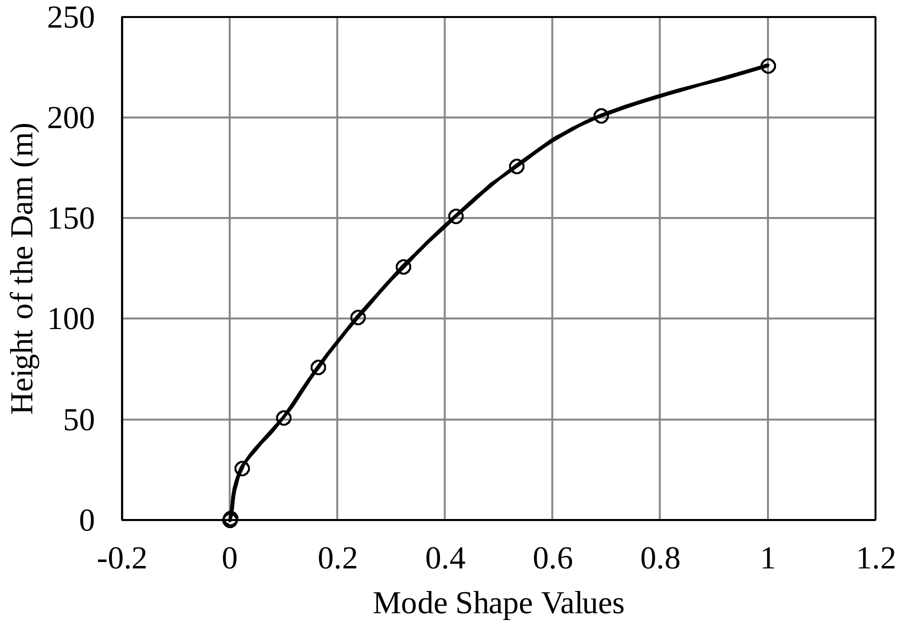
Table 4.3: Modal Properties of the Bhakra Dam

Mode No.	Periods (s)	Frequency (cps)	Modal Mass Ratio (%)
1	0.38	2.6	45
2	0.21	4.7	31
3	0.19	5.2	03
4	0.15	6.4	13
5	0.12	8.6	07

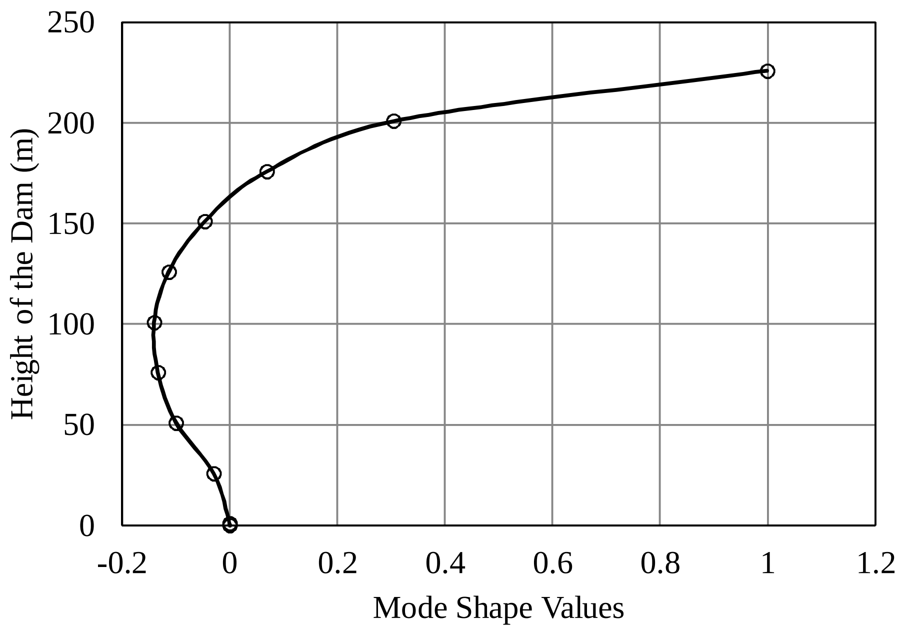
From table 4.3 we get the Modal Mass ratio for 1st mode is 45% and for the 2nd mode is 31%. It shows that unlike the building the modal mass for the 1st mode is not above 90% in case of dam. It is much less than that. So, in case of building we can take the 1st mode for the Calculation of Base Shear of the building. But in case of Dam it is not feasible. For Dam other modes are equally important. So, in case of Dam for the Calculation of Base Shear other Modes are also taken into account.

4.1.5 Mode Shapes of Bhakra Dam

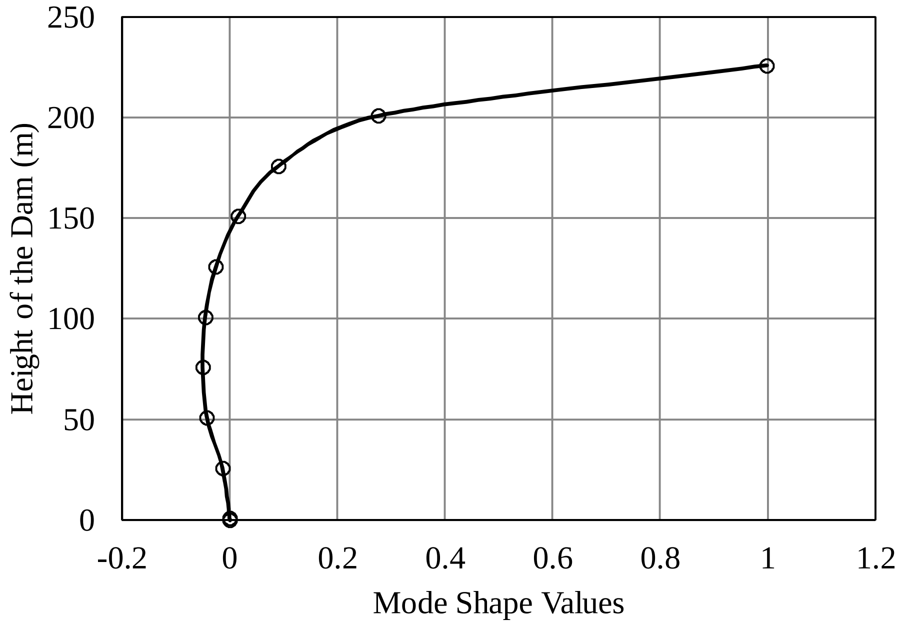
From Table 4.3, it can be seen that 1st mode contribution is no very dominant. In case of building the first mode shape itself gives the spatial distribution of the base shear over the height of the building. But these things we can’t accept from the dam. This is because other modes shapes including the 1st going to participate in the spatial distribution of base shear. In order to study this, five mode shapes of the Bhakra dam with its modal mass ratio is shown in Fig. 4.4.



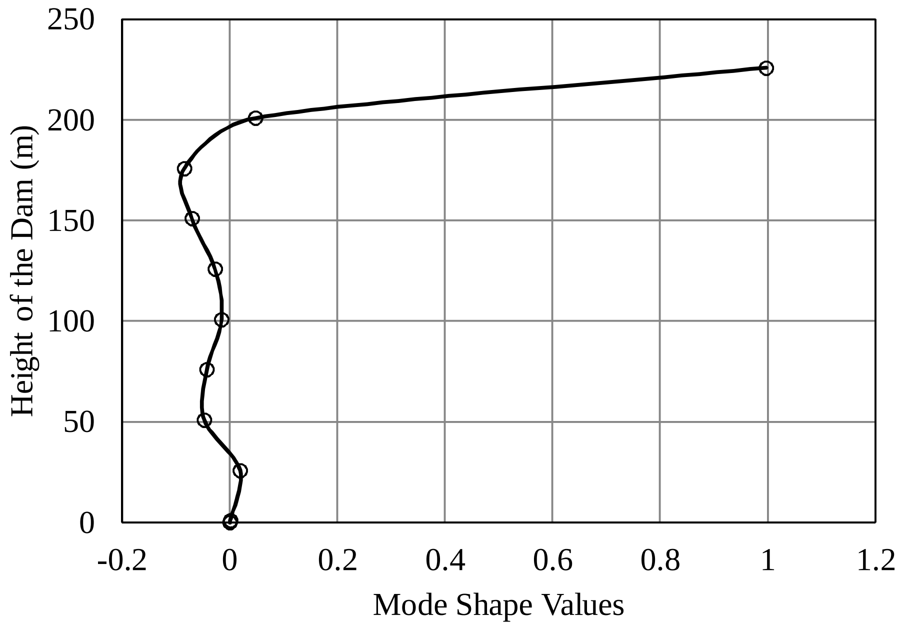
(a) 1st Mode Shape (UX=45%)



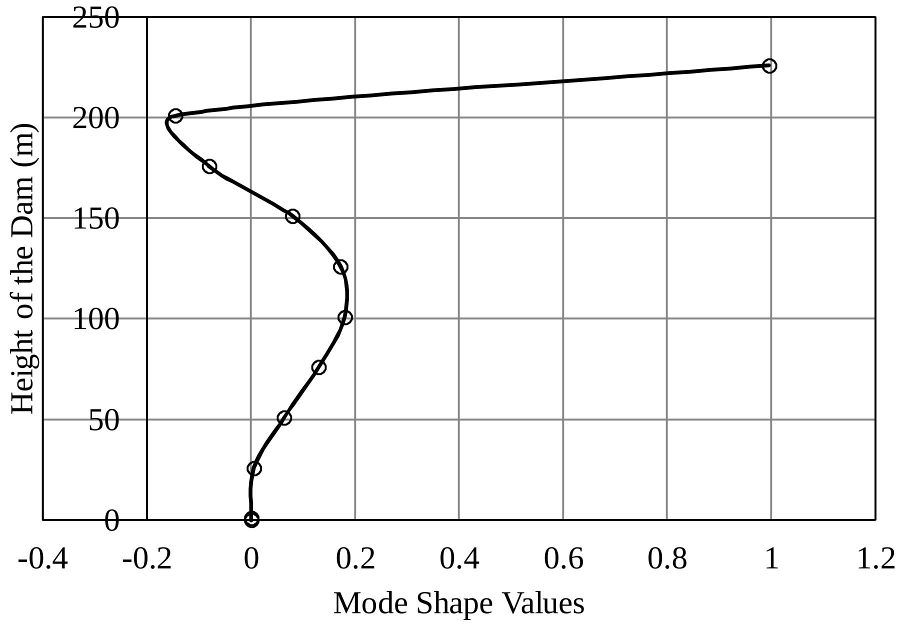
(b) 2nd Mode Shape (UX = 31%)



(b) 3rd Mode Shape (UX=3%)



(d) 4th Mode Shape (UX=13%)



(e) 5th Mode Shape (UX=7%)

Fig. 4.4: Different modes shapes of Bhakra Dam

4.2 SELECTED CONCRETE GRAVITY DAM

In order to get empirical formula for Natural Time period, a family of concrete gravity Dam is selected. The dams that are taken into consideration are of varies depth, base width and side slope. The detailed modal analysis procedure for dam is explained in Chapter 3. The height and base width of the selected dams are given in Table 4.4. After analyzing 10 dam, the modal mass ratio of all the dam of the different period is tabulated as shown in Table 4.5. Now the big question arises, how many modes are required to calculate the base shear? Table 4.5 will provide the answer of the above question. From Table 4.5, it can be conclude that the 1st and the 2nd mode of the dam are required for calculation of the Base Shear as it contribution is lies from 75%-95%. Other modes can be neglected as their contribution to the modal mass ratio is not very high. So, for the calculation of base shear first two natural time period are going to be used.

Table 4.4: Dimensions of Dams

Dam ID	Height (m)	Base Width (m) BW	Top Width (m) TW	Ratio=BW/TW
Dam 1	100	180	10	1.80
Dam 2	125	225	10	1.80
Dam 3	150	270	10	1.80
Dam 4	175	320	10	1.83
Dam 5	150	180	10	1.20
Dam 6	150	135	10	0.90
Dam 7	200	360	10	1.80
Dam 8	50	90	10	1.80
Dam 9	250	450	10	1.80

Table 4.5: Range of Modal Mass Ratio

Mode Number	Range of Modal Mass Ratio
1	45-55
2	35-50
3	0-15
4	0-15
5	0-10

4.3 ESTIMATION OF NATURAL PERIOD

4.3.1 Relation between Dam Height and Time Period

Each time it is not possible to calculate the natural time periods through ANSYS analysis. In order to simplify the problem, a relation between natural time period, height and base width is formulated. The relationship between the height and natural time period of the selected dams having constant slope (*i.e.*, 1.80) is shown in Table 4.6. In order to derive the relationship between height and time period, a plot between the dam height and time period is drawn as shown in Fig. 4.5. It can be seen from Fig. 4.5 that time period of dam increases with increase in height for a constant ratio of bottom width to height. Hence, it can be concluded that fundamental time period of dam is functions of its overall height.

Table 4.6: Relation between the dam height and time period

Height (m)	1st Period (s)	2nd Period (s)	3rd Period (s)
100	0.18	0.11	0.09
125	0.22	0.12	0.11
150	0.26	0.16	0.13
175	0.30	0.17	0.15
200	0.34	0.19	0.17
226	0.38	0.21	0.19

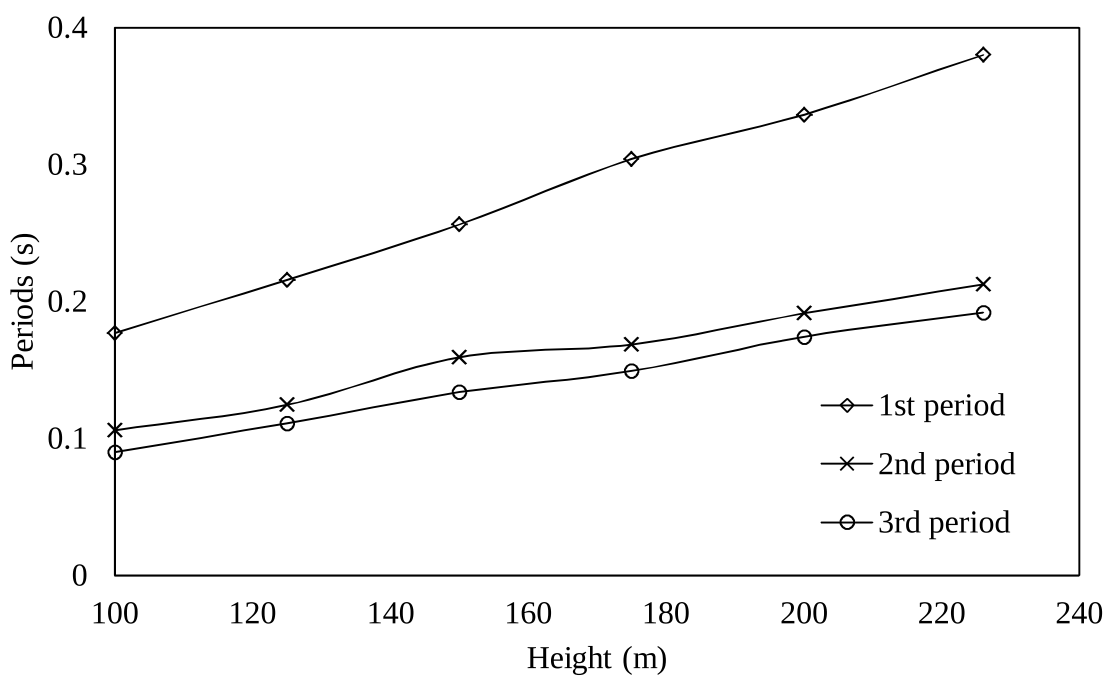


Fig 4.5: Plot between heights vs. period

4.3.2 Relation between the Base Width and Time Period

In the similar manner the relationship between the base width and natural time period is tabulated in Table 4.7. In order to have the relationship a plot between the base width and time period is drawn and presented in Fig. 4.6. It can be clearly seen from the Fig 4.6 that the 1st mode period of the dam decreases with increase in Base Width. The rate of decreasing is decreasing with increase in the base width .But in case of 2nd and 3rd mode period; the base width was found to have no influence. From this it can be conclude that the 1st mode period depends on Base Width but other higher mode periods are independent of base width.

Table 4.7: Relationship between Base Width and Time Period.

Base Width (m)	1st Period (s)	2nd Period (s)	3rd Period (s)
135	0.32	0.17	0.13
180	0.28	0.16	0.13
270	0.26	0.16	0.13

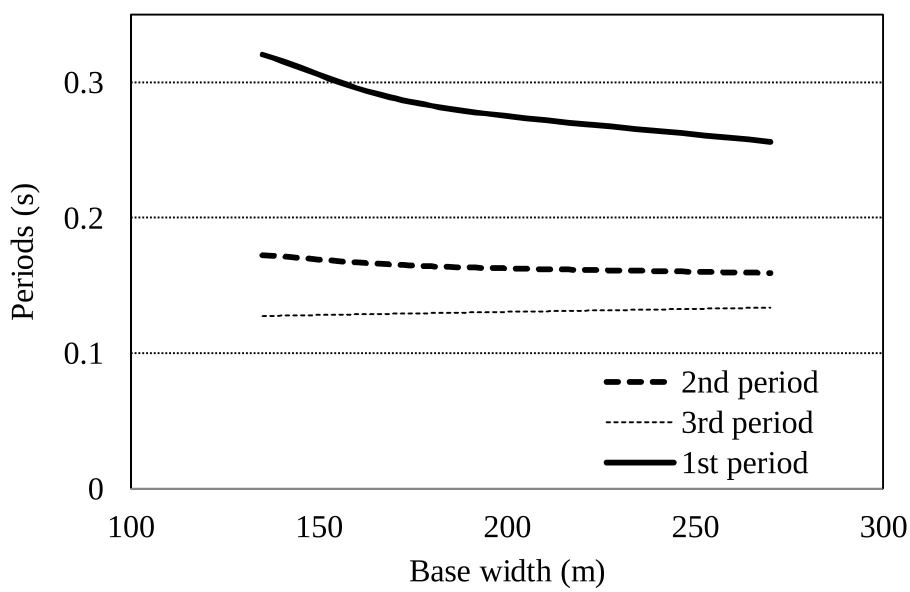


Fig 4.6: Plot between Base Widths vs. Periods

4.3.3 Formulation for Natural Time Period

A regression analysis is carried out on the data obtained from the selected dams. From Table 4.5, it can be seen that the first two periods are more important as its contribution to modal mass ratio is about 75%-95%. Because of that an empirical formula for the first two periods is formulated in this chapter. From Figs. 4.4-4.5, it can be clearly seen that the first natural time period depends on height and base width of the dam. But in case of second natural time period, it depends only on height of the dam. Thus the formula to calculate the first and second time period of a given dam is given by the Eq. (4.1) and Eq. (4.2) respectively.

$$T_1 = 0.0028 h^{1.3} b^{-0.35} \tag{4.1}$$

$$T_2 = 0.002 h^{0.86} \tag{4.2}$$

Where T_1 is the first natural time period of the dam, T_2 is the second natural time period of the dam, h is the height of the dam and b is the base width of the dam.

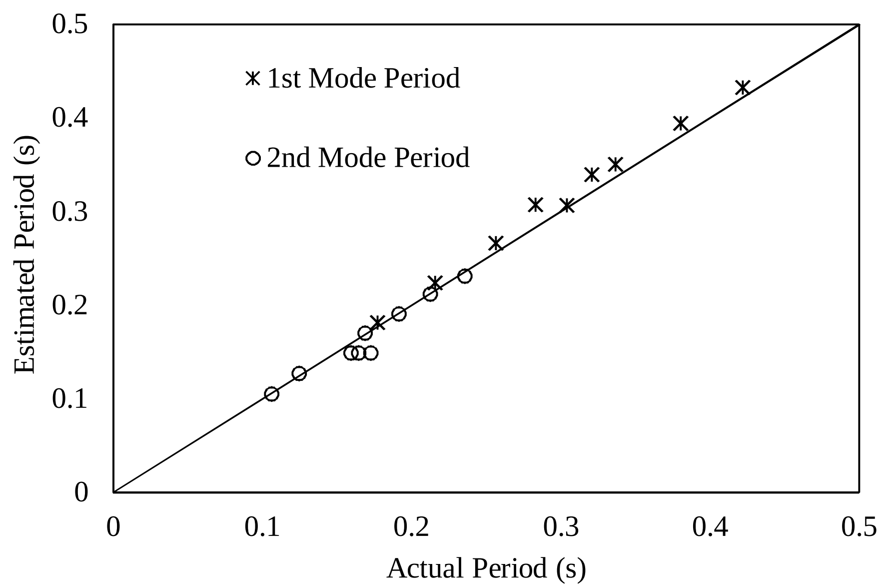


Fig 4.7: Plot between Actual periods vs. Predicted periods

In order to check the accuracy of the Eq. (4.1) and Eq. (4.2), a plot between the actual period and the estimated period is drawn. This plot can be seen in the Fig. 4.7. The actual period and the estimated period are almost lies near to each other when a 45^0 line is drawn in order to compare the deviation. This shows that the formula that has been derived in Eq. (4.1) and Eq. (4.2) give almost good result to real life problems.

4.4 CALCULATION OF BASE SHEAR

After having the empirical formula for natural time period, the next big thing is to "How to calculate the base shear?" According to IS 1893 Part-1, the Base Shear is calculated as given in Eq. (4.3).

$$V_B = A_h W \tag{4.3}$$

$$A_h = \left(\frac{Z}{2}\right)\left(\frac{I}{R}\right)\left(\frac{S_a}{g}\right) \tag{4.4}$$

Where V_B is the base shear of the dam, A_h is the horizontal seismic coefficient, W is the total weight of the dam, Z is the Zone Factor given in Table 2 of IS 1893 part 1, I is the Importance Factor given in Table 6 of IS 1893 part 1, R is the Response Reduction Factor and S_a/g is the spectral acceleration coefficient.

The above formula is also applicable for the dam as it is calculated for the single degree of freedom system. Now, the problem is how to calculate the horizontal seismic coefficient. The value of Z and I can be obtained from IS 1893 Part 1. The value of R can be taken as 4 because of the brittle nature of the dam. S_a/g value can be obtained from the Fig 4.8 corresponding to its period. In case of building first natural time period is dominating. So, corresponding to the first period S_a/g value is calculated from Fig. 4.8. But in case of dam both the first and second time period are important. Hence, how to calculate the S_a/g value for the dam is explained in the next section.

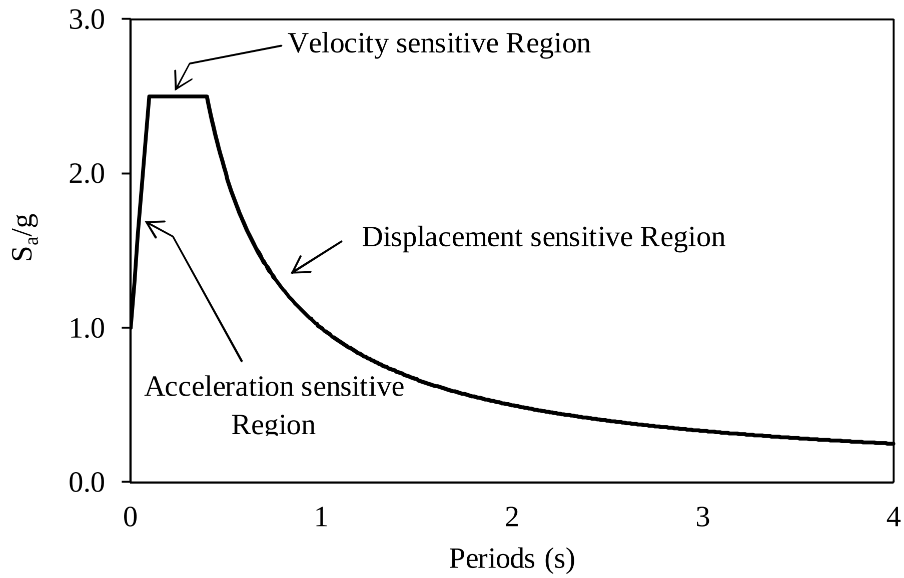
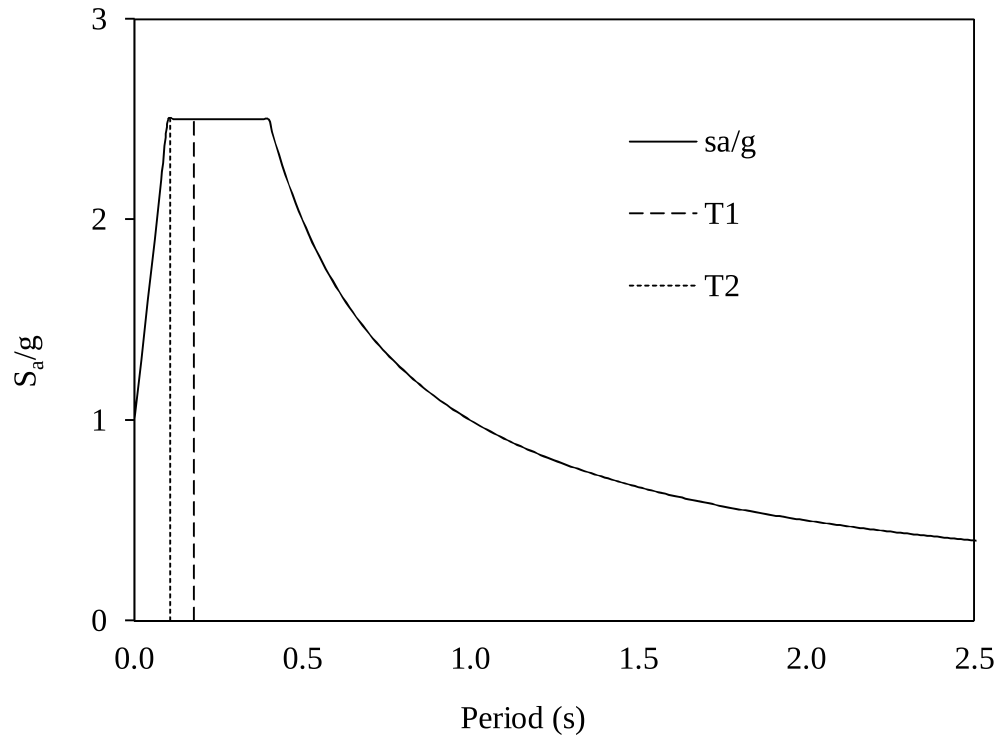


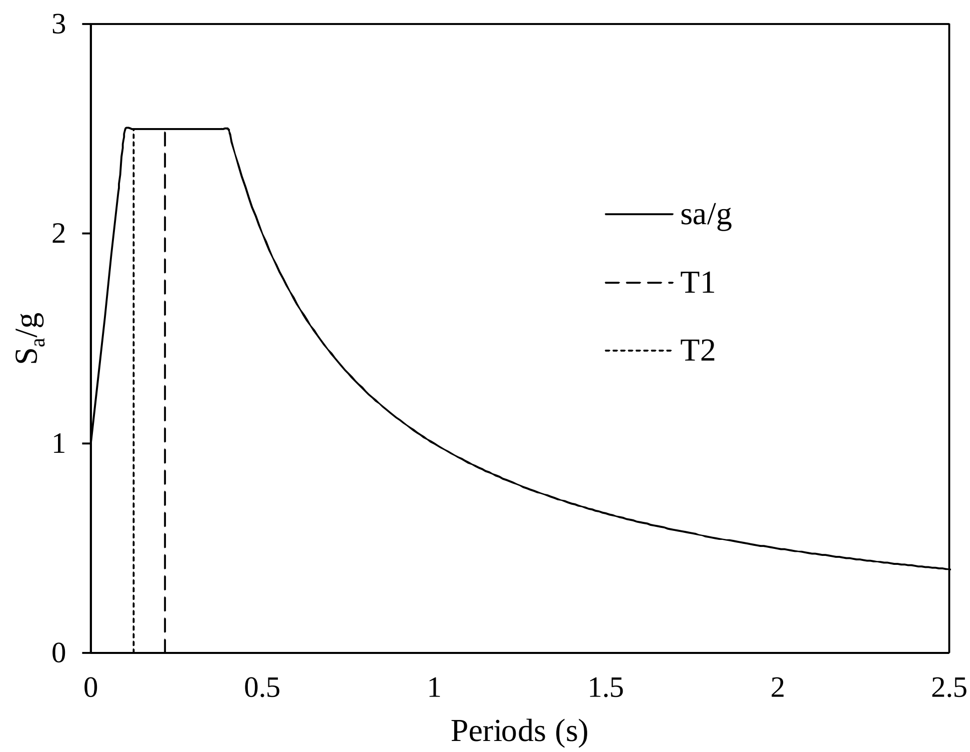
Fig. 4.8 Response Spectra for Rock and Hard Soil Sites for 5 Percent Damping

4.5 CONTRIBUTION OF IMPORTANT MODES

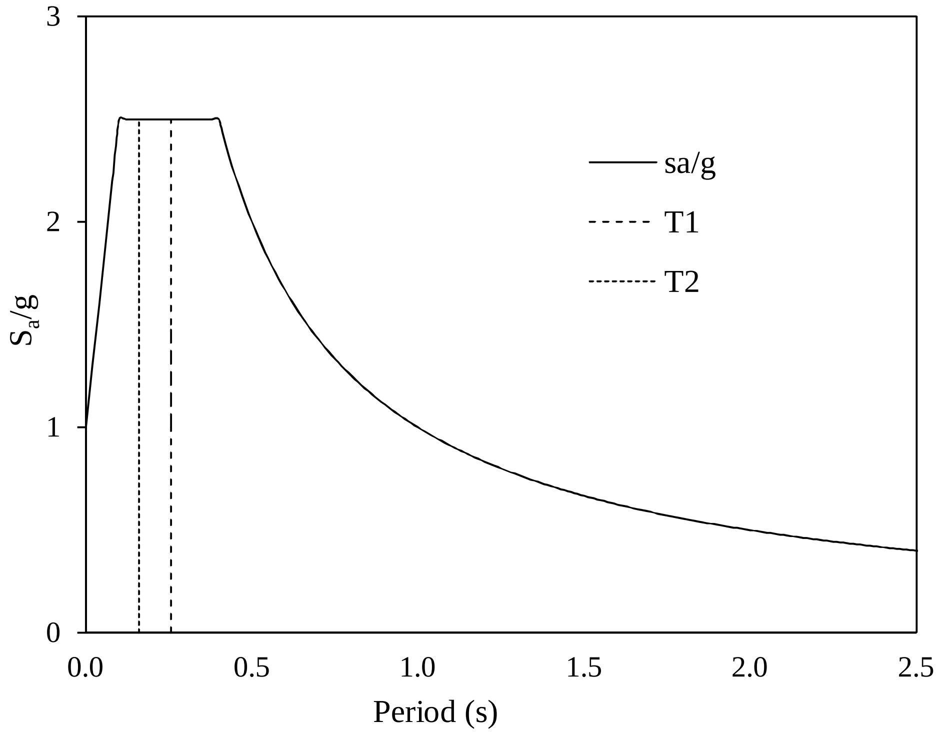
In order to formulate the S_a/g value for the dam, a study on the selected dam is done. It can be seen from Fig. 4.9 that if the time periods lie in the velocity sensitive region then first time period is used to get the horizontal seismic coefficient of the dam. But if it lies in the acceleration sensitive region and displacement sensitive region then both of the time periods (*i.e.*, first and second mode period) are required to calculate the horizontal seismic coefficient of the dam.



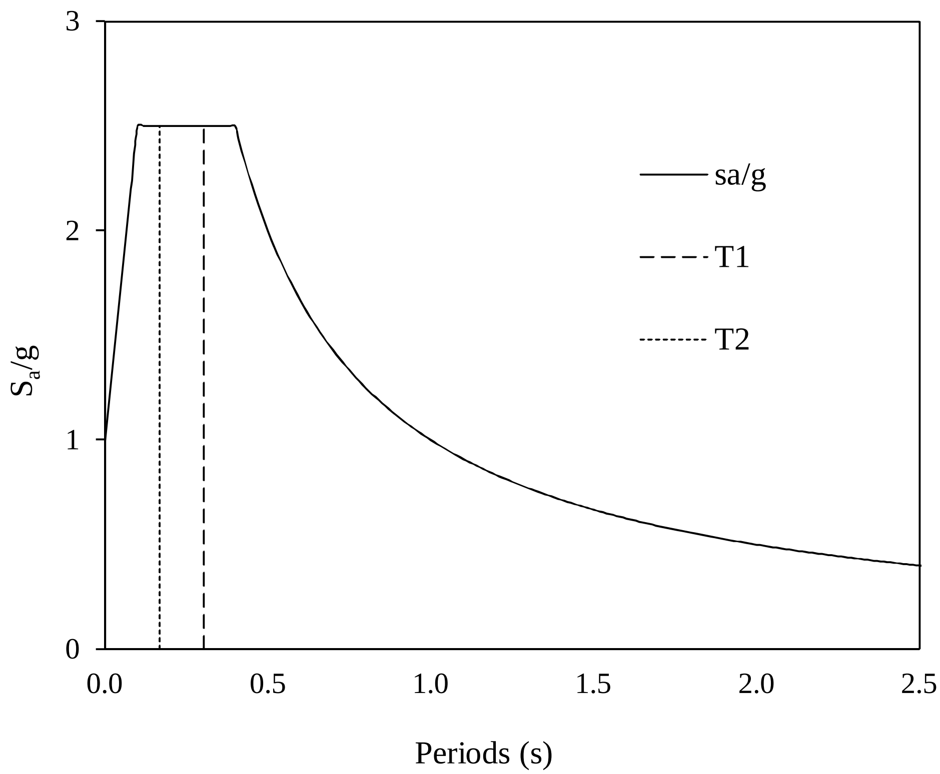
(a) Dam 1 (Height=100 m, Slope=1.0:1.8)



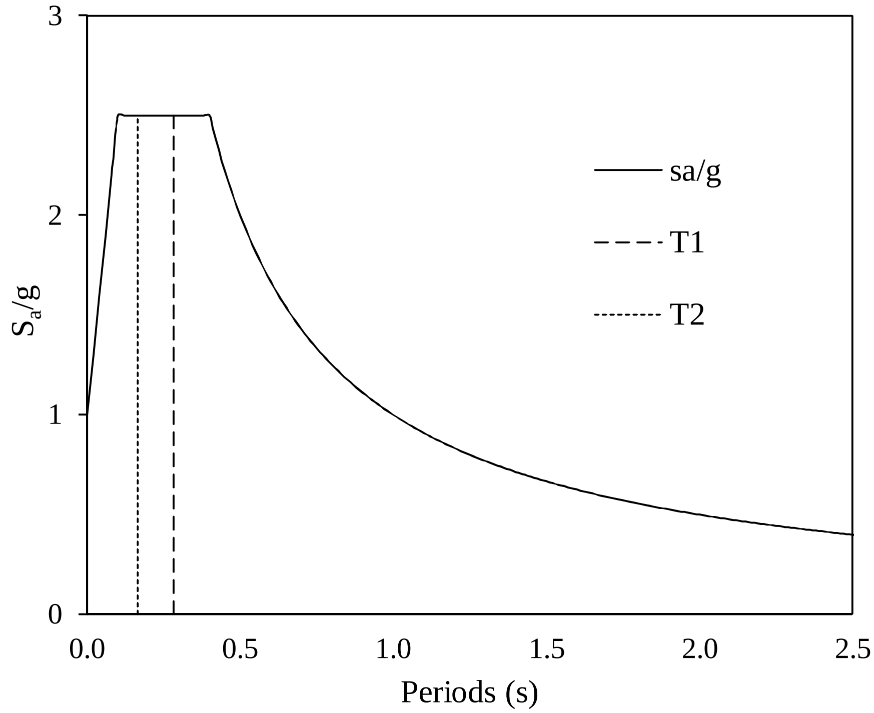
(b) Dam 2 (Height=125 m, Slope=1.0:1.8)



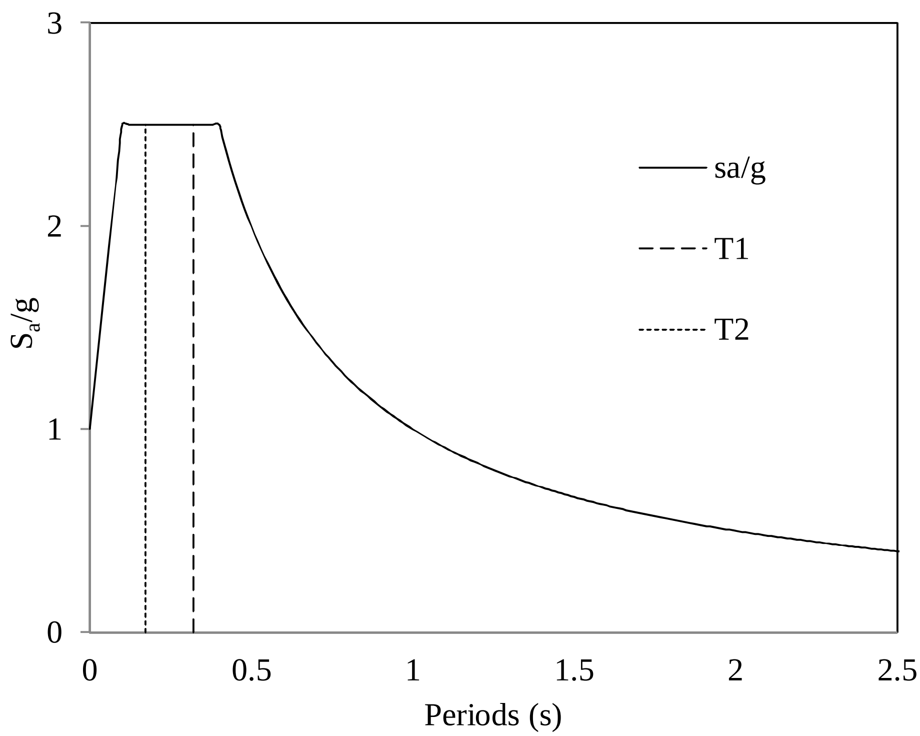
(c) Dam 3 (Height=150 m, Slope=1.0:1.8)



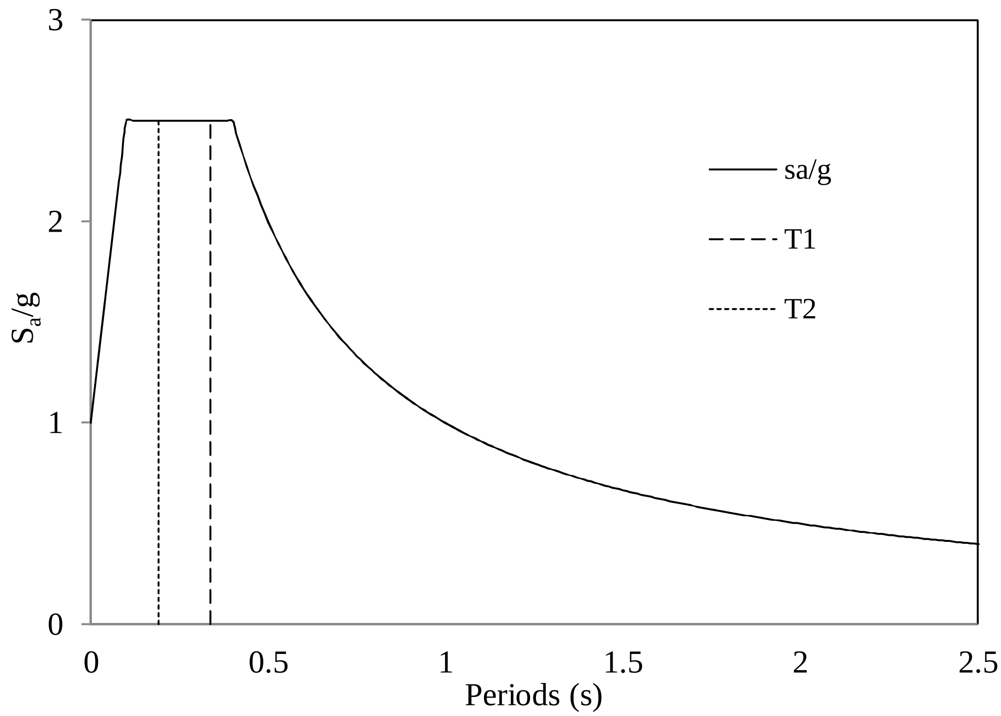
(d) Dam 4 (Height=175 m, Slope=1.0:1.83)



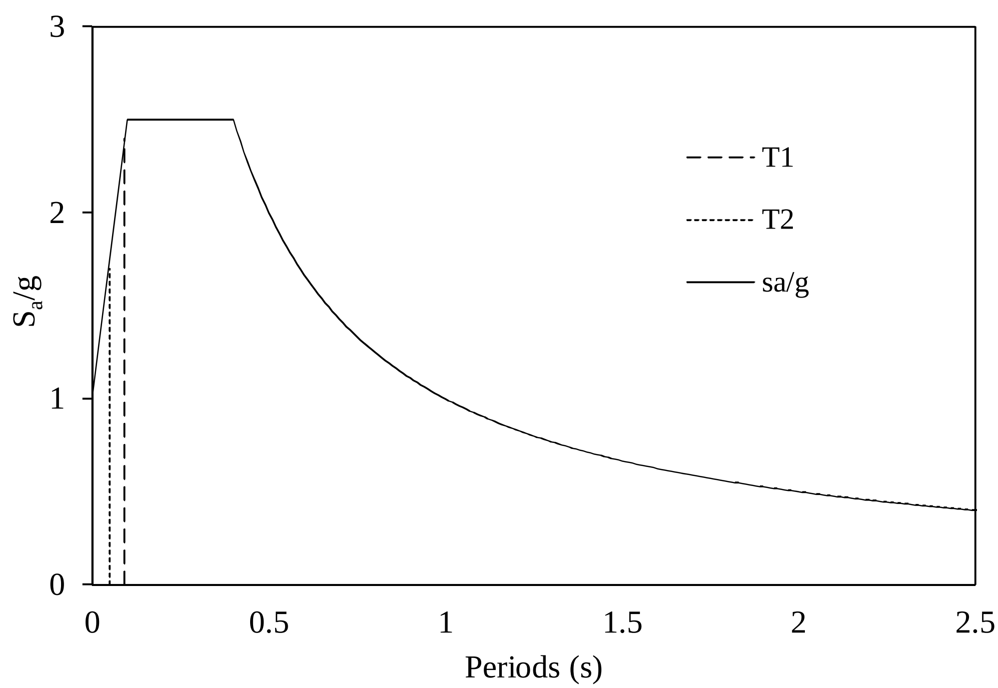
(e)Dam 5 (Height=150 m, Slope=1.0:1.20)



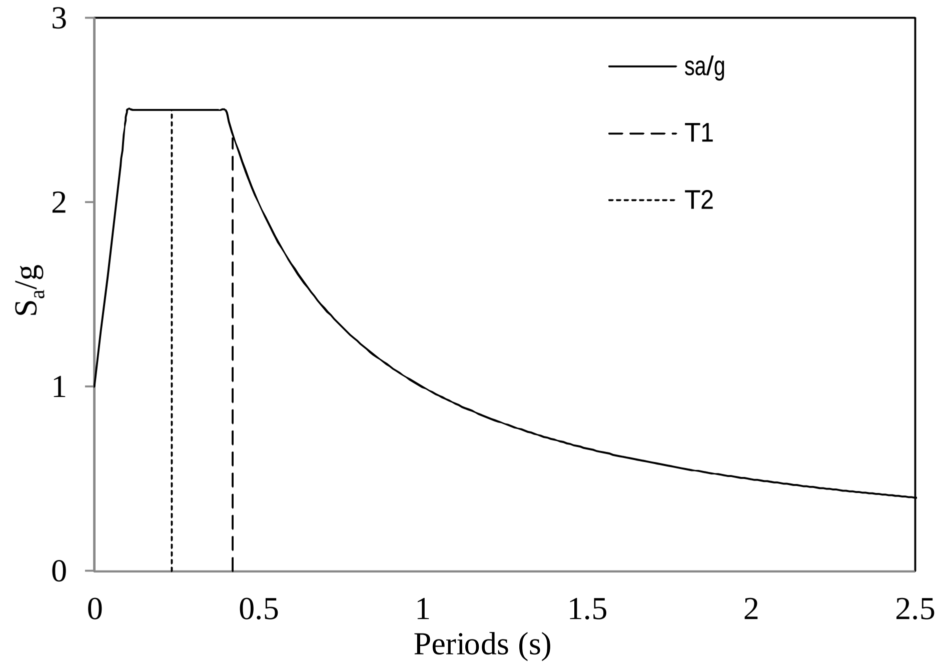
(f) Dam 6 (Height=150 m, Slope=1.0:0.9)



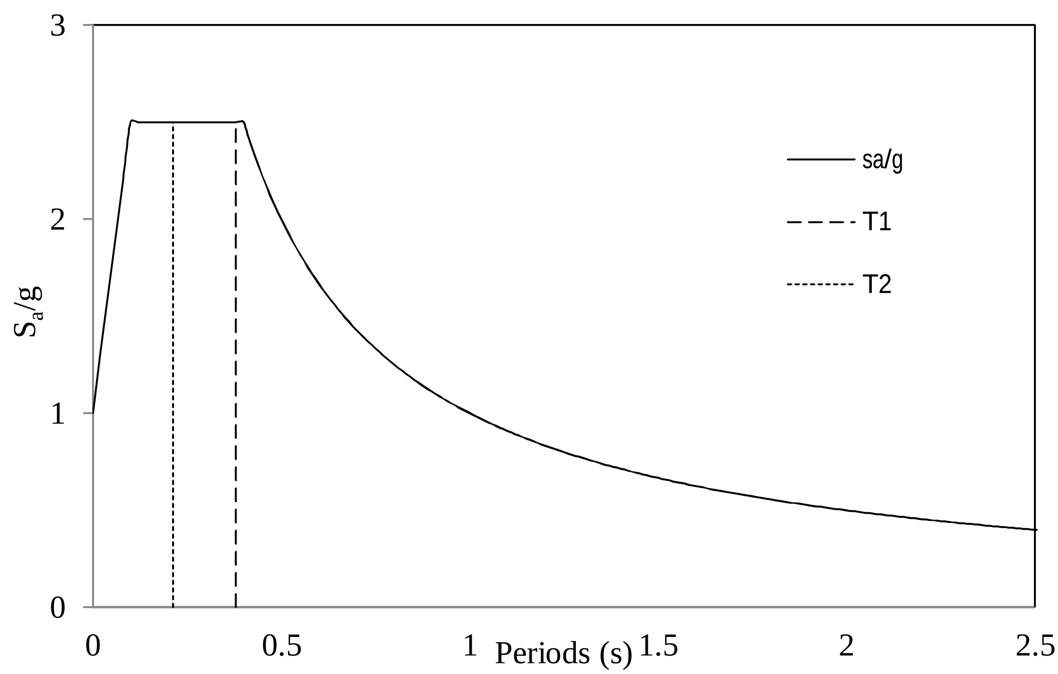
(g) Dam 7 (Height=200 m, Slope=1.0:1.80)



h) Dam 8 (Height=50 m, Slope=1.0:1.8)



(i) Dam 9 (Height=250 m, Slope=1.0:1.80)



(j) Dam 10 (Bhakra Dam)

Fig. 4.9: Spectral acceleration (S_a/g) values for selected dam

4.6 ESTIMATION OF BASE SHEAR

From Fig. 4.9, it can be observe that if the time periods lie in the acceleration sensitive region; then there will be a lot of variation in the S_a/g value for different time periods. Similar is the case for the displacement sensitive region. But for the velocity sensitive region the value of S_a/g remains nearly constant. Taking all this into account the base shear is calculated as follows:

A. If both the periods lie in velocity sensitive region, use the 1st mode period only as shown in Eq. (4.5) to calculate the Base Shear

$$V_B = A_{h1}W \tag{4.5}$$

B. If 2nd mode period lies in acceleration sensitive region, use Eq. (4.6) to calculate base shear

$$V_B = (0.6A_{h1} + 0.4A_{h2})W \tag{4.6}$$

C. If 1st mode period lies in displacement sensitive region, use Eq. (4.7)

$$V_B = (0.4A_{h1} + 0.6A_{h2})W \tag{4.7}$$

4.7 SPATIAL DISTRIBUTION OF BASE SHEAR

The empirical formula that is used for the spatial distribution of base shear over the height of the building is given in the section 7.7.1 of IS 1893 part 1. The first mode shape of the building is similar to spatial distribution of base shear. This gives an idea of how to calculate the spatial distribution of base shear in case of dam. In order to check the likeness of the formula a plot between the normalized height value and normalized height is drawn as shown in the Fig. 4.10. From the Fig. 4.10 we can see that at the crest level the displacement of selected dams are more than the Spatial Distribution followed by the IS 1893 part 1. So, the modified Spatial Distribution for the Dam is given in the Eqs. (4.8) and (4.9). The Eq. (4.9) represents the point load that is acting over the crest of the dam in order to take into account the crest level displacement.

$$Q(h) = \frac{A(h)h^2}{\int_0^H A(h)h^2 dh} V_B \tag{4.8}$$

$$P_{crest} = 0.01V_B \tag{4.9}$$

Where *Q(h)* represent the force at height *h* meter from the base of the dam, *H* is the height of the Dam and V_B is the design base shear of the dam.

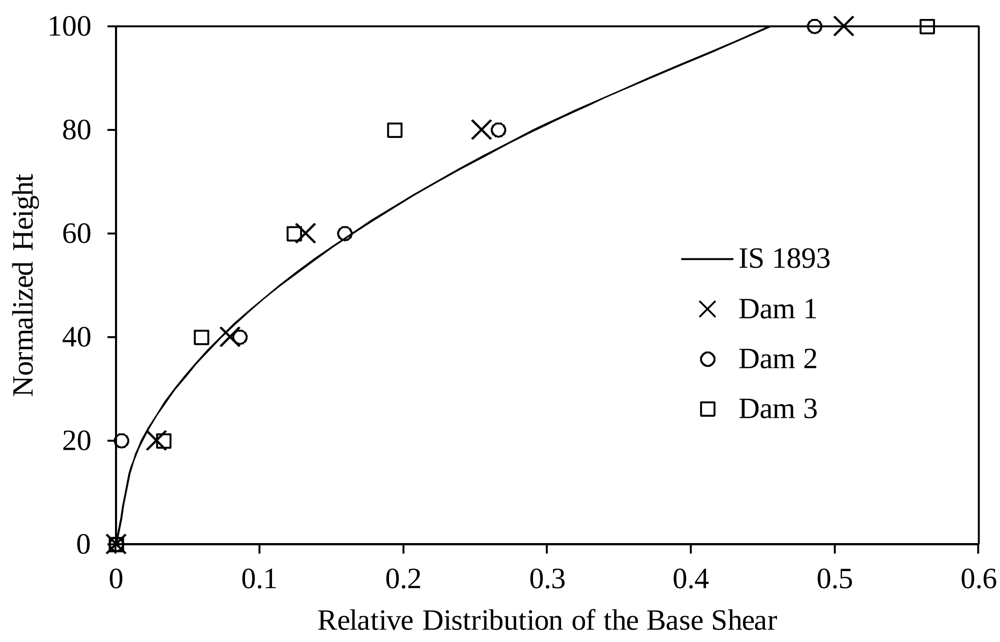


Fig 4.10: Relative Distribution of the Base Shear along the height.

CHAPTER ~ 5

SUMARRY AND CONCLUSION

5.1 SUMMARY

The objective of the present report was to develop an equivalent static method for seismic analysis of concrete gravity dam suitable for design office. It includes the method to calculate fundamental period, design of base shear and vertical distribution of base shear along the height of the dam.

A family of concrete gravity Dam is taken into account for the analysis. In order to simulate the problem to real life, an existing concrete gravity dam (Bhakra Dam, India) is taken for analysis. The 2D model of the Dam is analyzed using finite element analysis in commercial software ANSYS 13.0. The modal parameters of the selected dam obtained from the analysis have been studies and an empirical formula has been proposed to calculate the *natural time period* and *base shear* through regression analysis. A spatial distribution of the base shear over the height is also proposed. The method proposed in the present study to evaluate the seismic base shear and analyze the dam subjected to seismic loading is computationally simple and can be included in the design code.

5.2 CONCLUSION

The conclusions presented here are limited to the salient contributions made in the present study:

i) A formulation for estimation fundamental period of concrete gravity dam is proposed based on dynamic analysis of a family of concrete gravity dam of varying dimensions.

ii) A procedure is developed to estimate the design base shear of concrete gravity dam that includes the higher mode effect.

iii) A new approach for spatial distribution of base shear along the height of the dam is proposed.

This procedure is computationally attractive for the designers.

5.3 SCOPE OF FUTURE STUDY

i) The present study has not considered the value of response reduction factor for the dam structure. However, response reduction factor is important aspect of seismic design and the values given in the IS 1893:2002 are for the building structure only. There is the scope to study detail about the response reduction factor with regard to Concrete Gravity Dam.

ii) This procedure can be extended for other category of dams (*e.g.*, Arch dam, etc.).

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